Themes in Celestial CFT

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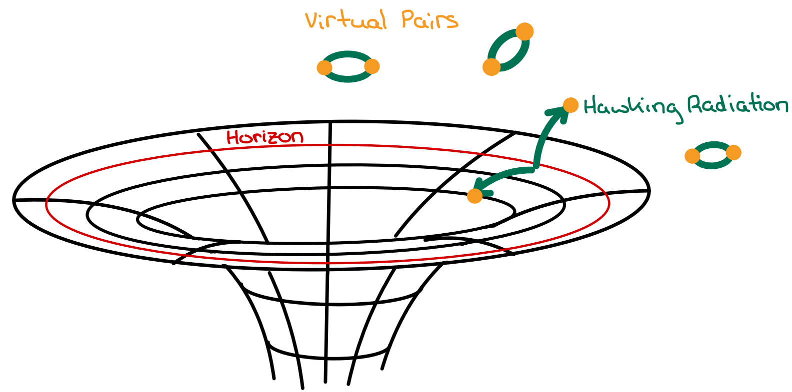
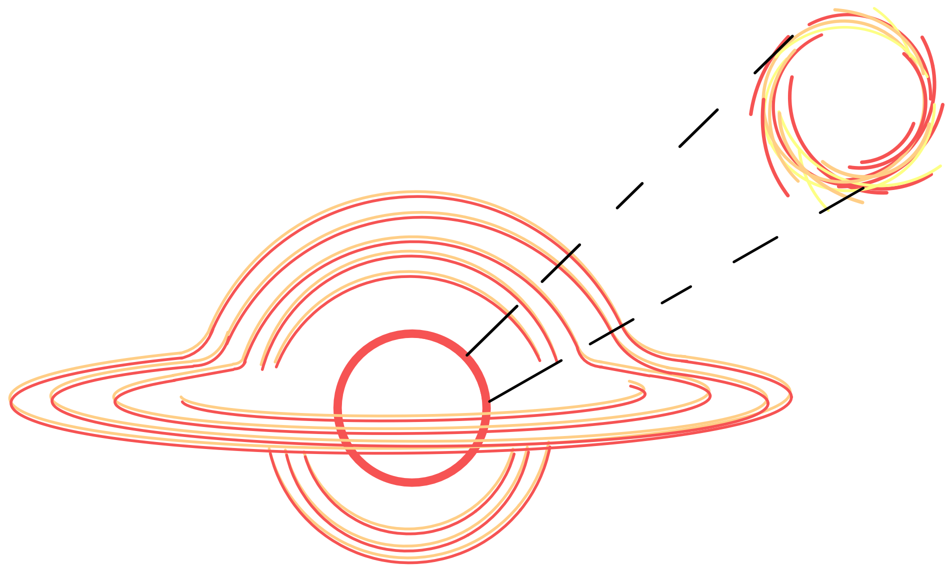
The holographic principle states that a quantum theory of gravity can be described as a lower dimensional theory without gravity.

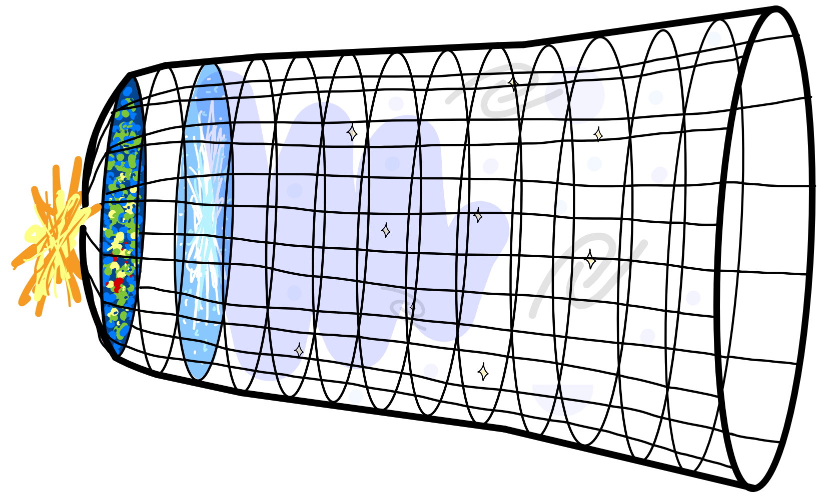
$$S_{BH} = \frac{c^3 \, \text{Area}_{\text{Horizon}}}{4 G_N \hbar}$$



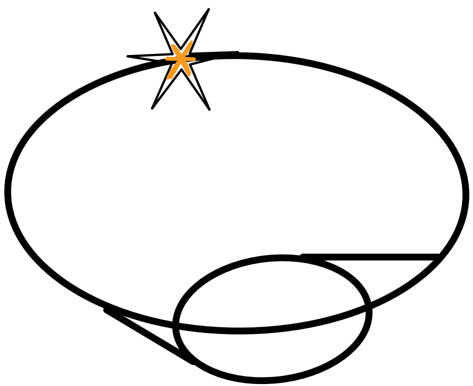
A classic success story is the AdS/CFT correspondence. We would like to be able to apply this framework to astrophysically relevant contexts.



If we zoom in near the horizon of a rapidly rotating black hole we get a region that we can model with Anti-de Sitter space $\Lambda<0$.



In the real world $\Lambda > 0$, so we would need a de Sitter/CFT correspondence to describe physics at cosmological scales.



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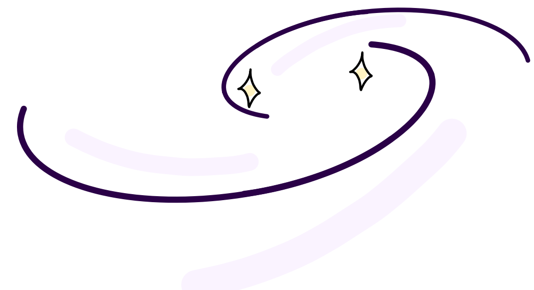
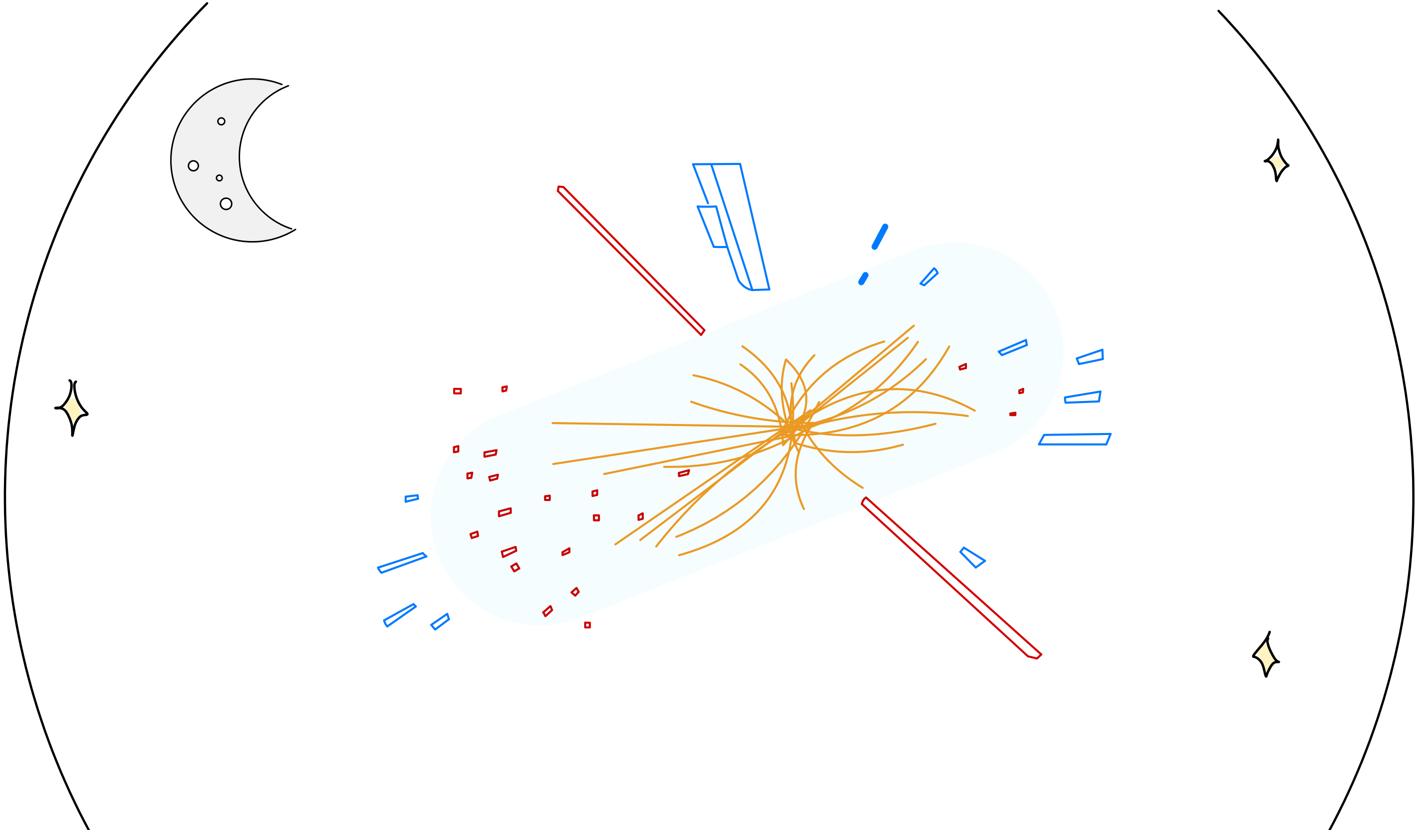


Physics on intermediate scales is well approximated by $\Lambda = 0$.

Celestial Holography proposes a duality between gravitational scattering in asymptotically flat spacetimes and a CFT living on the celestial sphere.



Synopsis

The advantage of this program is that it reorganizes scattering in terms of symmetries.

In particular, an ∞-dimensional enhancement coming from the asymptotic symmetry group.

Outline/ Checklist

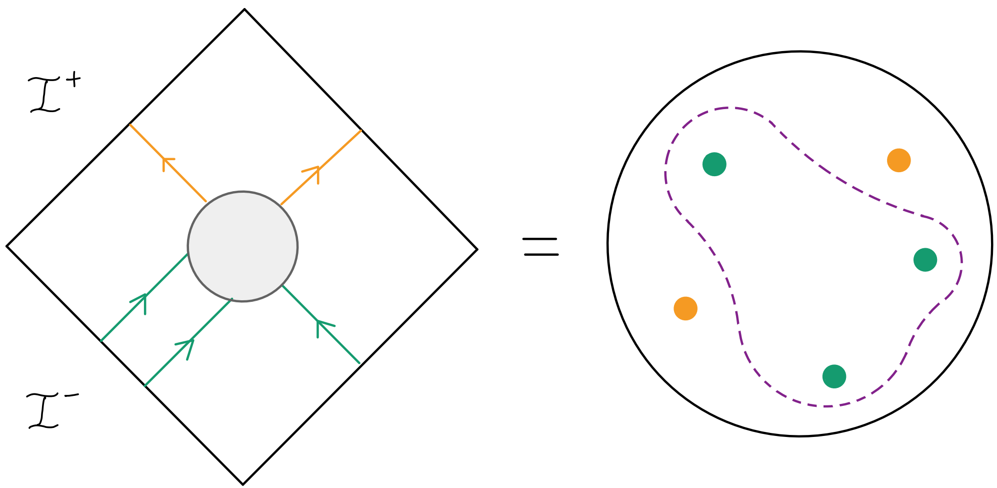
1. The case for CCFT

2. A little help from SUSY

3. Ongoing questions

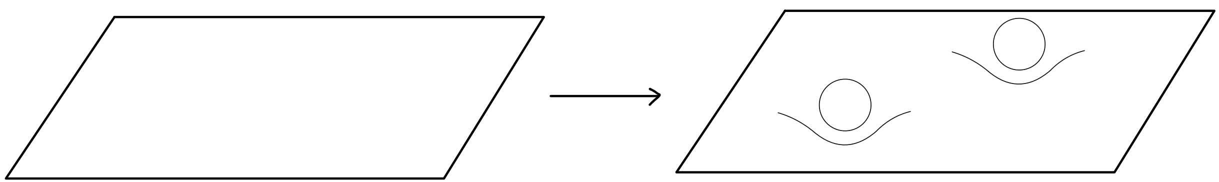
Goal: Apply the holographic principle to $\Lambda=0$ quantum gravity.

Plan: Celestial Holography proposes that the natural dual system lives on the celestial sphere.



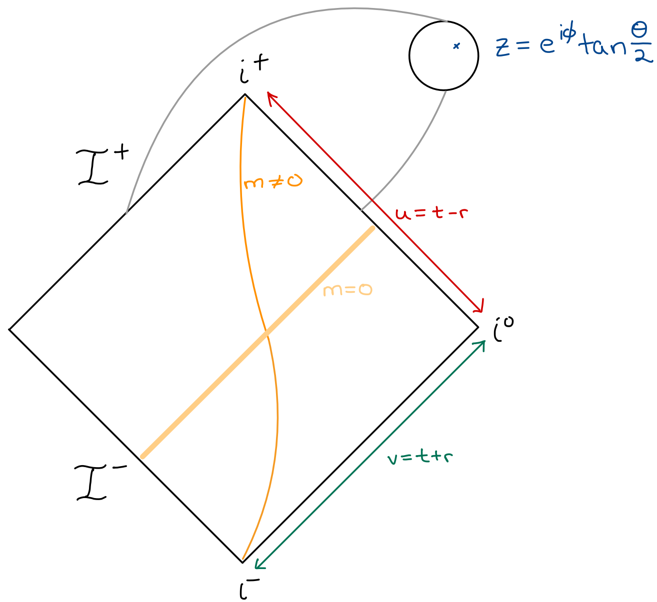
We are interested in scattering in asymptotically flat spacetimes.

$\Lambda = 0 \qquad T_{\mu\nu} \neq 0$



$$ds^2 = -dt^2 + dx^2 + dy^2 + dz^2$$

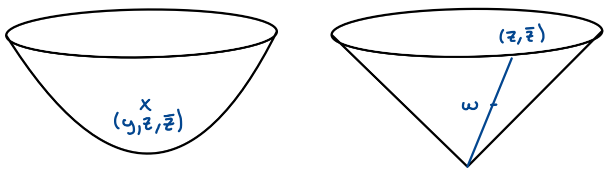
These spacetimes have the same asymptotic causal structure as Minkowski space.



In particular massless excitations enter and exit along null hypersurfaces $\mathcal{I}^\pm \cong \mathbb{R} \times S^2$.
We will refer to this S^2 cross-section as the celestial sphere in what follows.

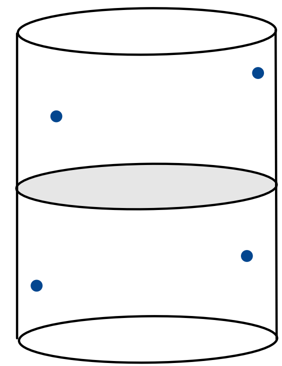
We can merge aspects of the two standard precedents for our hologram...

$\langle \text{out} | S | \text{in} \rangle$



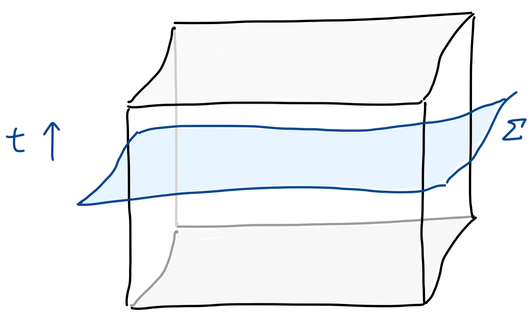
$p^2 = -m^2$ $\quad$ $p^2 = 0$

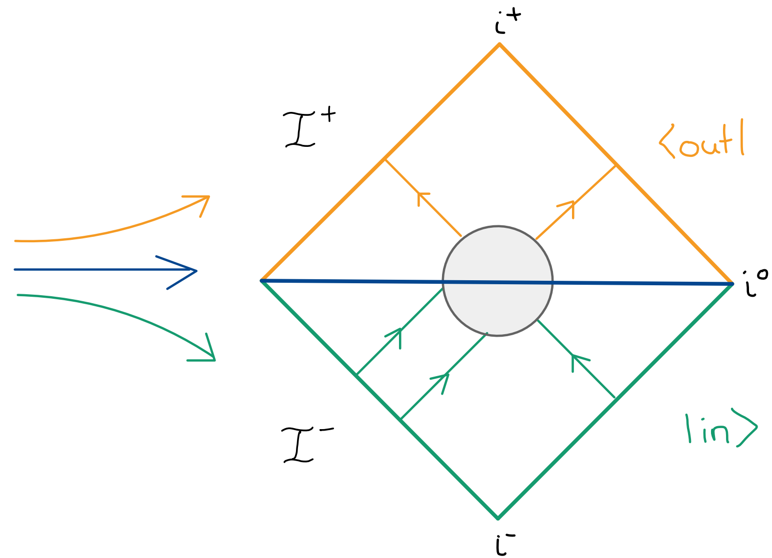
AdS/CFT



$\Lambda < 0$

... by pushing our Cauchy slice to scri to prepare the in and out states with operators on the boundary.



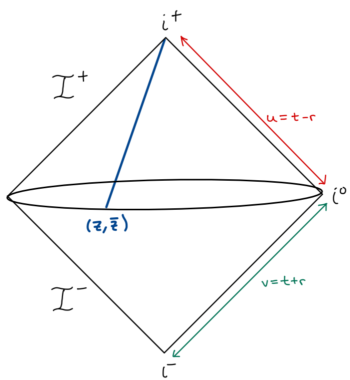


For example taking $r \to \infty$, u- fixed the plane wave localizes...

$$e^{ip\cdot X} = e^{-ip^0 u - ip^0 r(1-\cos\theta)} \longrightarrow e^{-ip^0 u} \times \frac{i}{p^0 r} \frac{\delta(\theta)}{\sin\theta}$$

... and we can prepare an $m=0$ momentum eigenstate with the boundary limit of our bulk operator smeared on a generator of $\mathcal{J}^+$.

$$h_{\mu\nu} = \sum_{\alpha=\pm} \int \frac{d^3p}{(2\pi)^3} \frac{1}{2p^0} \left[\varepsilon^{\alpha *}_{\mu\nu} a_\alpha e^{ip\cdot X} + \varepsilon^{\alpha}_{\mu\nu} a^\dagger_\alpha e^{-ip\cdot X} \right]$$



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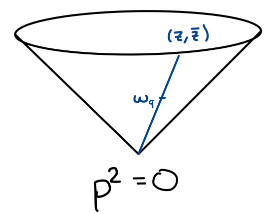
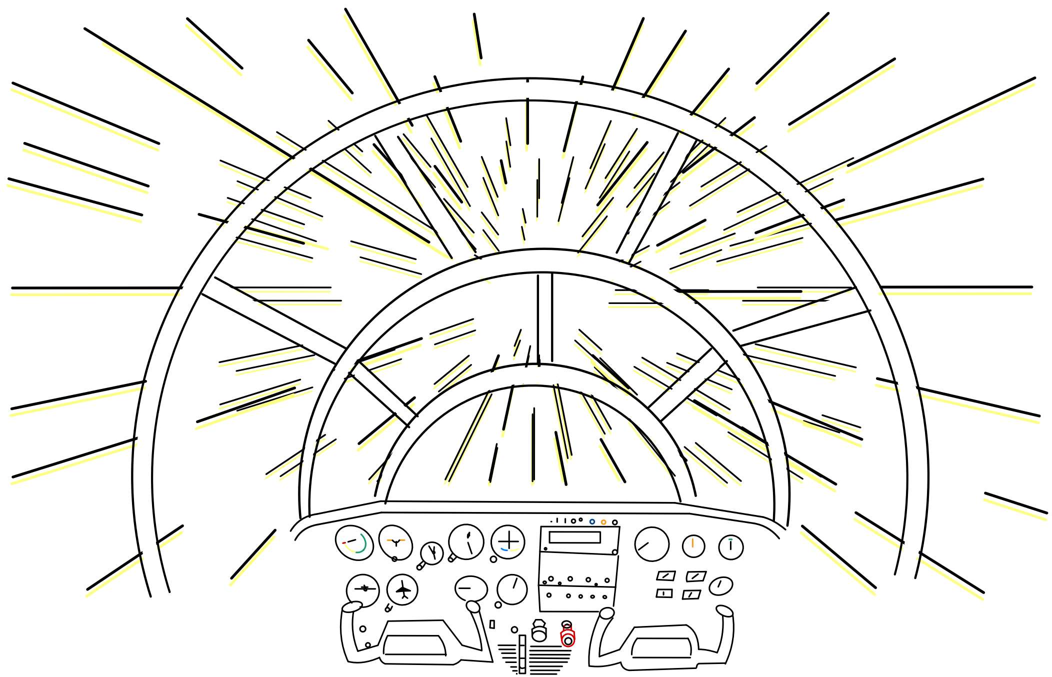




Lorentz transformations of Minkowski Space act as global conformal transformations on the celestial sphere.

So we can map 4 D S-matrix elements to 2D correlators by choosing appropriate wave packets that prepare boost eigenstates

$$\langle p_{out,i} | S | p_{in,j} \rangle \longmapsto \langle \mathcal{O}^{+}_{\Delta_i, J_i} \cdots \mathcal{O}^{-}_{\Delta_j, J_j} \cdots \rangle$$

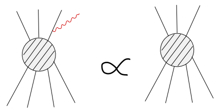
When m=0 this is just a Mellin transform

$$\tilde{A}(\Delta_i, z_i, \bar{z}_i) = \prod_{i=1}^{n} \left(\int_0^{\infty} d\omega \, \omega^{\Delta_i - 1} \right) A(\omega_i, z_i, \bar{z}_i)$$

Themes

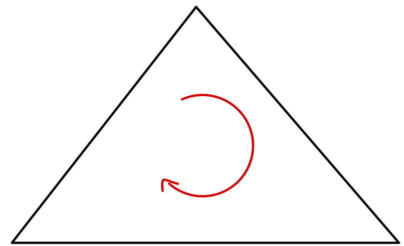
It is beneficial to examine both the asymptotic spacetime and amplitudes manifestations of a given structure.

CCFT further advocates for a particular dimensional reduction because it elucidates a larger symmetry algebra.



Universal behavior as $\omega \to 0$ in QFT

Soft Theorems



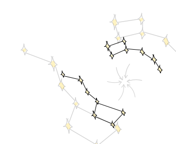
We can use this template to find new examples.

Memory Effects

Asymptotic Symmetries

Net detector displacements

Richer space of vacua



We want to understand how bulk quantities behave near the boundary. Outgoing radiation is captured by the metric at large r, fixed u=t-r.

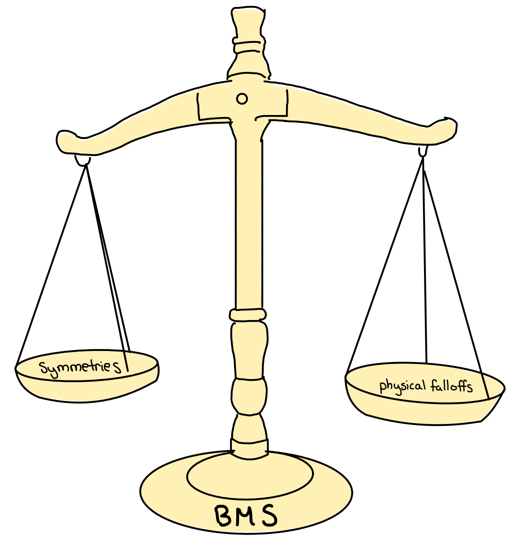
$$ds^2 = -du^2 - 2dudr + 2r^2\gamma_{z\bar{z}}\,dz d\bar{z}$$ ← flat

$\frac{1}{r^{\#}}$ corrections

$$+\frac{2m_B}{r}du^2 + rC_{zz}dz^2 + rC_{\bar{z}\bar{z}}d\bar{z}^2 + D^zC_{zz}dudz + D^{\bar{z}}C_{\bar{z}\bar{z}}dud\bar{z} + \ldots$$

To study the phase space and symmetries one needs to

- pick a convenient gauge
- specify physical falloffs
- identify residual transformations that preserve these falloffs



Residual diffeomorphisms that preserve the falloffs and act non-trivially on the asymptotic data are part of the Asymptotic Symmetry Group.

$$ASG = \frac{\text{Allowed Symmetries}}{\text{Trivial Symmetries}}$$

The ASG will be much larger than the group of isometries of any given spacetime within this class.

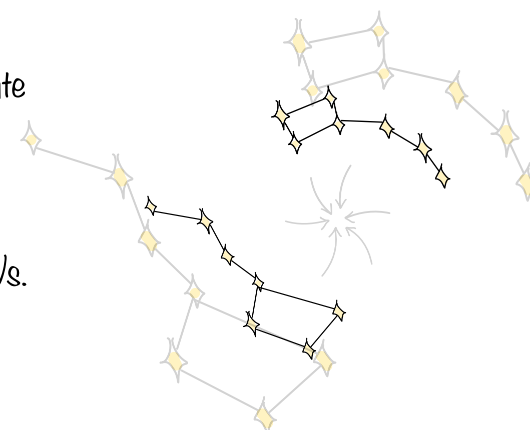
$$\begin{array}{lccc} & \text{Poincaré} & \subset & \text{BMS} \\ \#\text{generators:} & 10 & & \infty \end{array}$$

- Supertranslations induce angle-dependent shifts in the time coordinate

$$\xi|_{\mathcal{I}^+} = f(z,\bar{z})\,\partial_u$$

- Superrotations extend global conformal transformations to local CKVs.

$$\xi|_{\mathcal{I}^+} = Y^z(z)\,\partial_z + \frac{u}{2} D_z Y^z(z)\,\partial_u + c.c.$$



The proposal to allow superrotations

prompted Cachao and Strominger to look for a subleading soft graviton thm

and led to the identification of a new memory effect.

Meanwhile it's ward Identity promotes the Lorentz group to a Virasoro symmetry

with this soft graviton mode providing a candidate 2D stress tensor

in the boost basis

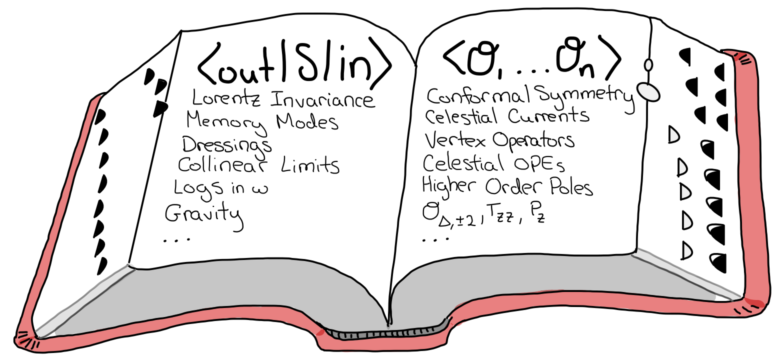
Canonical phase space methods also predict the form of the loop corrections

The celestial basis actually points to a full tower of soft modes whose collinear limits encode a $Lw_{1+\infty}$ symmetry!

The celestial holographer wants to bootstrap amplitudes from their soft and collinear limits.

- The soft limits turn into poles in the weights.

- Meanwhile collinear limits of scattering translate into a celestial OPE.



SUSY shout-out

- Soft thm $\Leftrightarrow$ Ward Identity more general than examples with gauge constraints
- Wherever SUSY helps with Amplitudes it helps with Celestial Amplitudes.
- Analogously to the stress tensor, a supercurrent can be constructed form the soft gravitino.

Ongoing Questions

- Role of IR regulators $\longrightarrow$ non-zero levels
  - $\longrightarrow$ deforming symmetry algebra
- Analytic Continuations $\longrightarrow$ crossing between in and out
  - $\longrightarrow$ crossing between 2D channels
- Toy Models $\longrightarrow$ identifying necessary ingredients
  - $\longrightarrow$ SSB governed soft sector

Thank You!