Title: Grad Student Seminar: Elisa Tabor

Speakers: Elisa Tabor
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Abstract: A brief introduction to Celestial Holography

We introduce the origins of holography and illustrate in broad strokes the theory of celestial holography. We discuss the development of asymptotic symmetries from soft theorems and how these symmetries point to a codimension 2 boundary on which would live the dual CFT. We show the connection between predicted asymptotic symmetries and observable memory effects, completing the famous infrared triangle. We conclude with some applications and current problems we are thinking about, in particular with respect to bulk reconstruction.

A brief introduction to Celestial Holography

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Perimeter Institute

November 2022

Roadmap

Holography

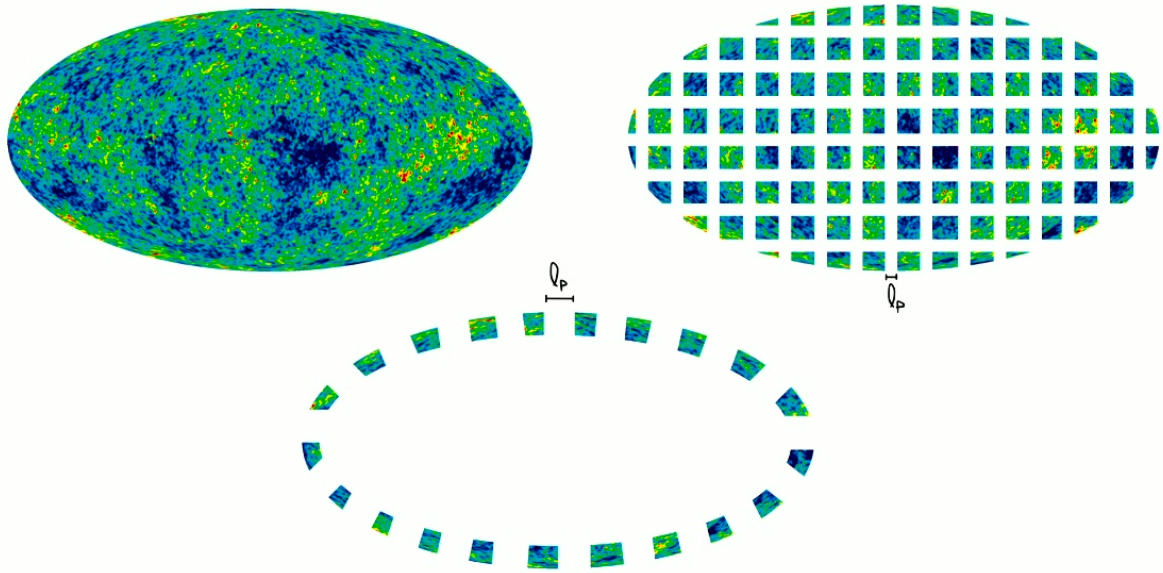
Penrose

Symmetries

Soft theorems

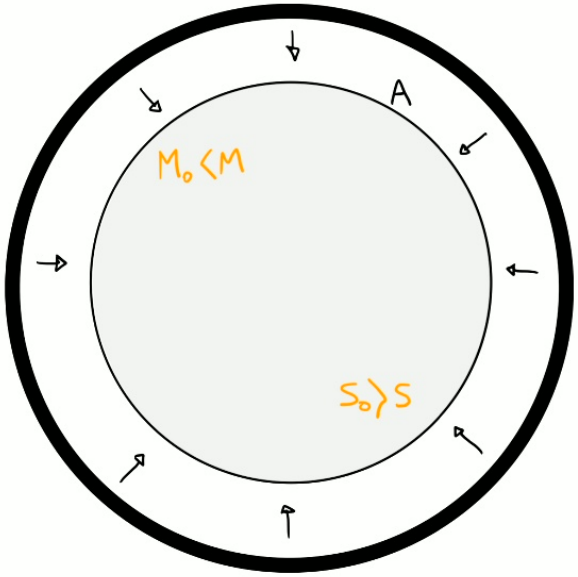
Holographic map

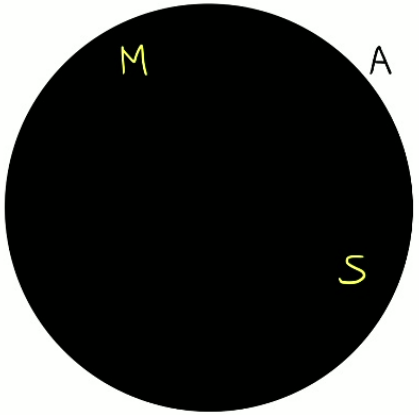
What is holography?



[1]['t Hooft '93, 9310026]

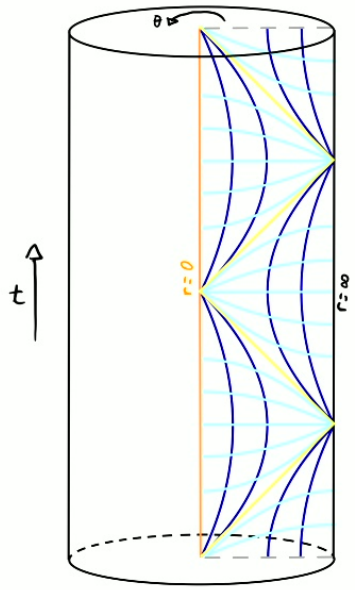
Maximal entropy of volume is $S_{BH} = \frac{A}{4}$





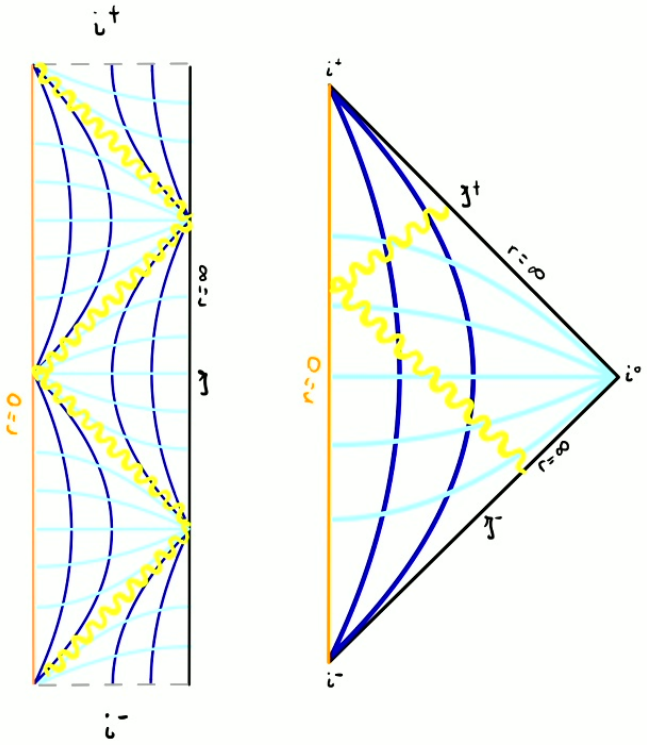
[2][Susskind '94, 9409089]

Successful application to AdS/CFT



[3] [Maldacena '98, 9711200]

AdS vs. Minkowski



[3] [Maldacena '98, 9711200]

Standard Minkowski metric

$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega_2^2$$

Standard Minkowski metric

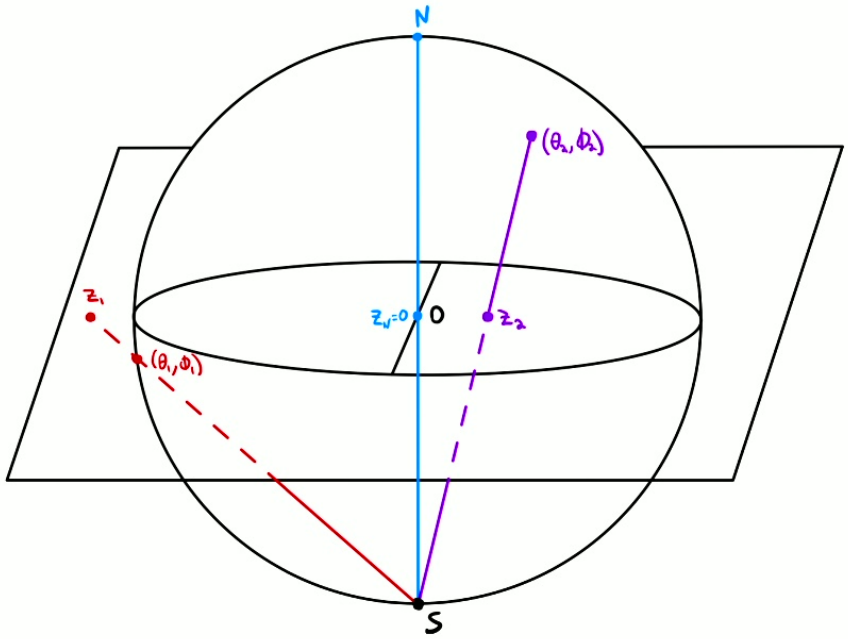
$$ds^2 = -dt^2 + dr^2 + r^2 d\Omega_2^2$$

Coordinate change

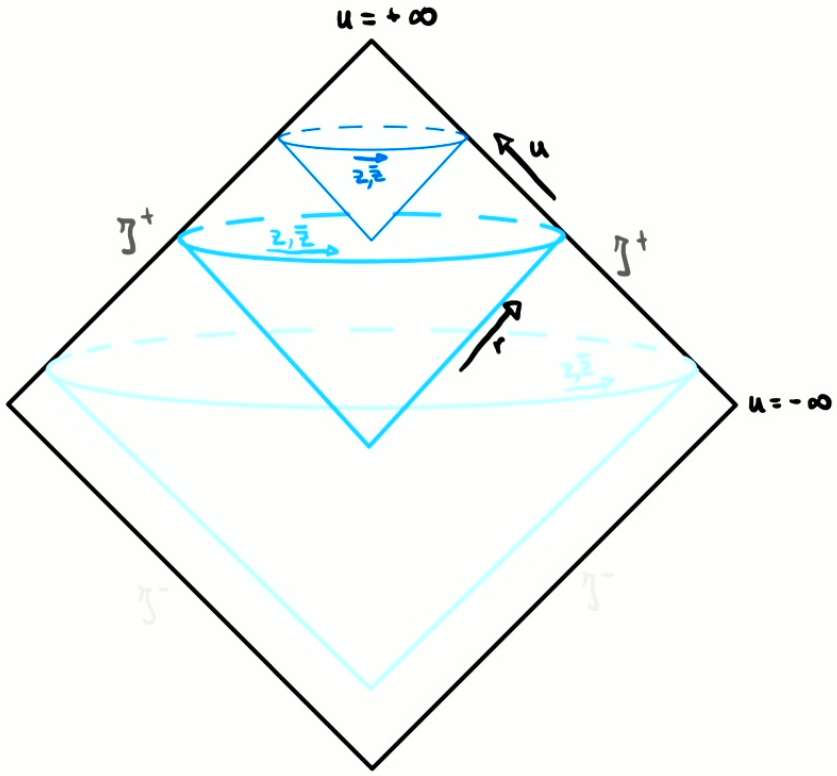
$$u = t - r, \quad v = t + r$$

$$z = \cot\frac{\theta}{2} e^{i\phi}, \quad \bar{z} = \cot\frac{\theta}{2} e^{-i\phi}$$

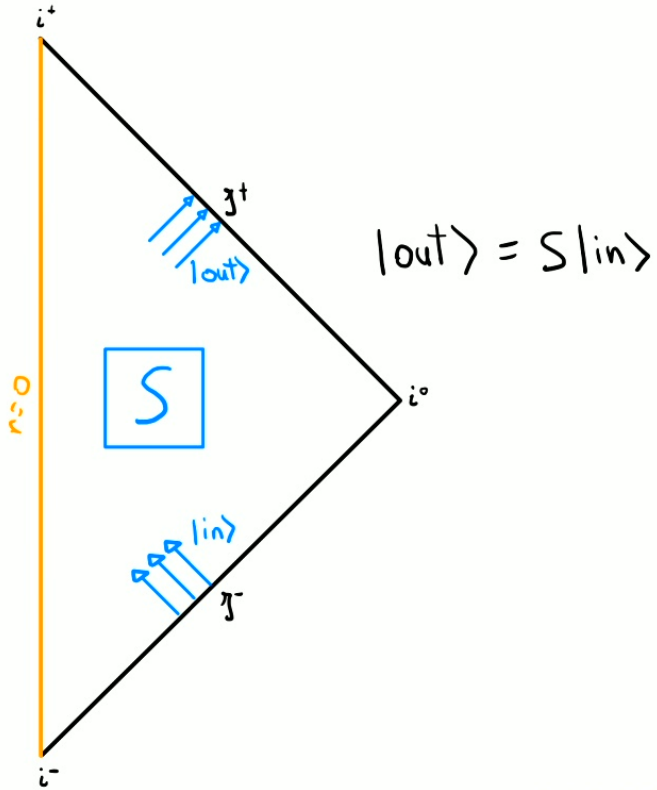
Stereographic projection



Visualizing new coordinates on Penrose diagram

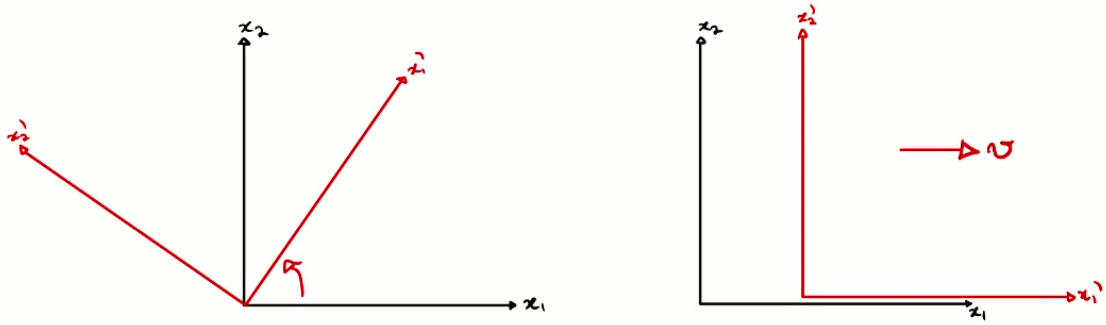


Language to describe boundary



$$|out\rangle = S|in\rangle$$

Lorentz group

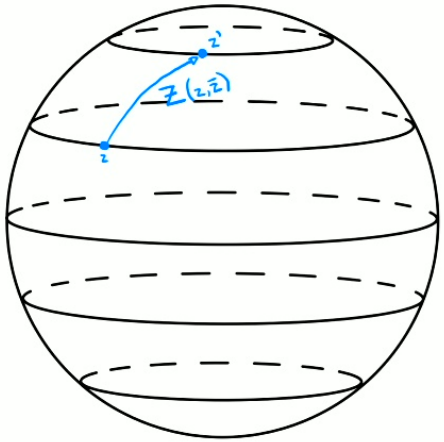


$$L_+^{\uparrow} \cong SL(2,\mathbb{C})/\mathbb{Z}_2$$

$$SL(2,\mathbb{C}) = \left\{ \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in M(2,\mathbb{C}) \middle| ad - bc = 1 \right\}$$

[4] [Oblak '18, 1508.00920]

Conformal transformations on 2-sphere

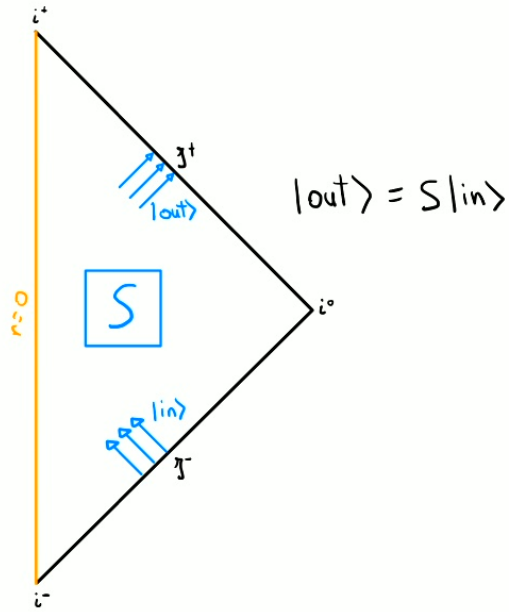


$$\phi : S^2 \to S^2 : z \mapsto Z(z, \bar{z})$$

$$Z(z) = \left. \frac{az + b}{cz + d} \right|_{ad-bc=1}$$

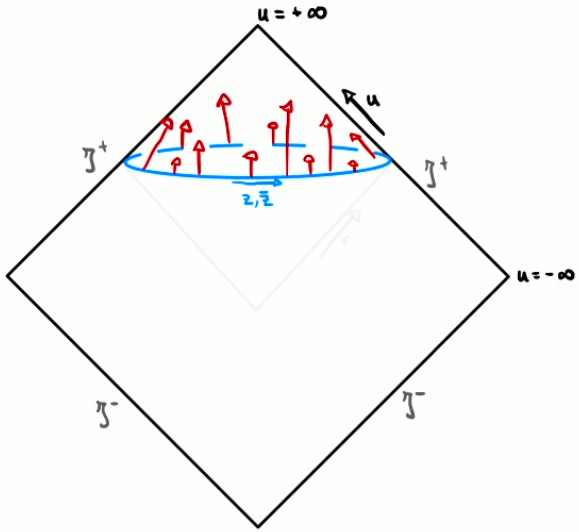
[5] [Oblak '18, 1508.00920]

There exist many more Minkowski symmetries



$^*|\text{out}\rangle = S\,|\text{in}\rangle$ up to asymptotic symmetries

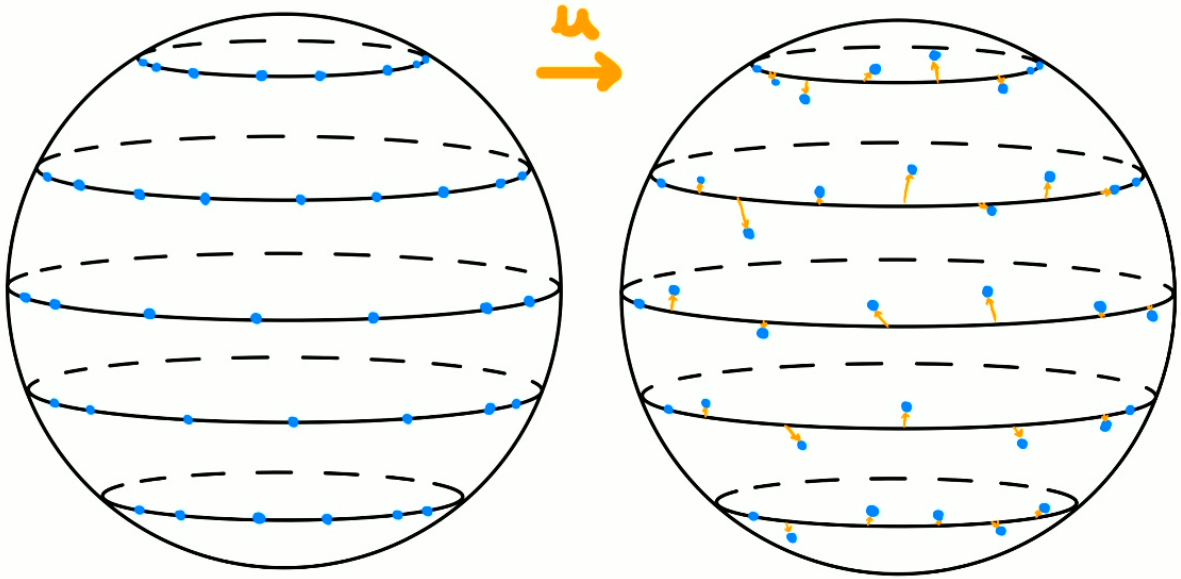
Supertranslations definition



angle dependent translations on cross sections at $\mathcal{I}^+$, in u direction

[6] [Bondi, van der Burg, Metzner, Sachs '62, Gravitational waves in GR, vii.&viii.]
[7] [He, Lysov, Mitra, Strominger '15, 1401.7026]

Supertranslations illustrated on 2-sphere



Preview: superrotations from soft theorems

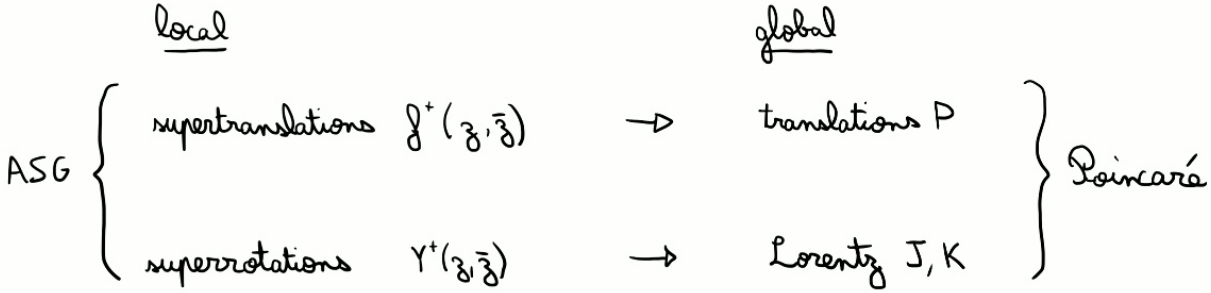
supertranslations $f^+(z,\bar{z})$ $\Rightarrow$ soft graviton theorem

$\downarrow$

superrotations $Y^+(z,\bar{z})$ $\Leftarrow$ subleading soft graviton theorem

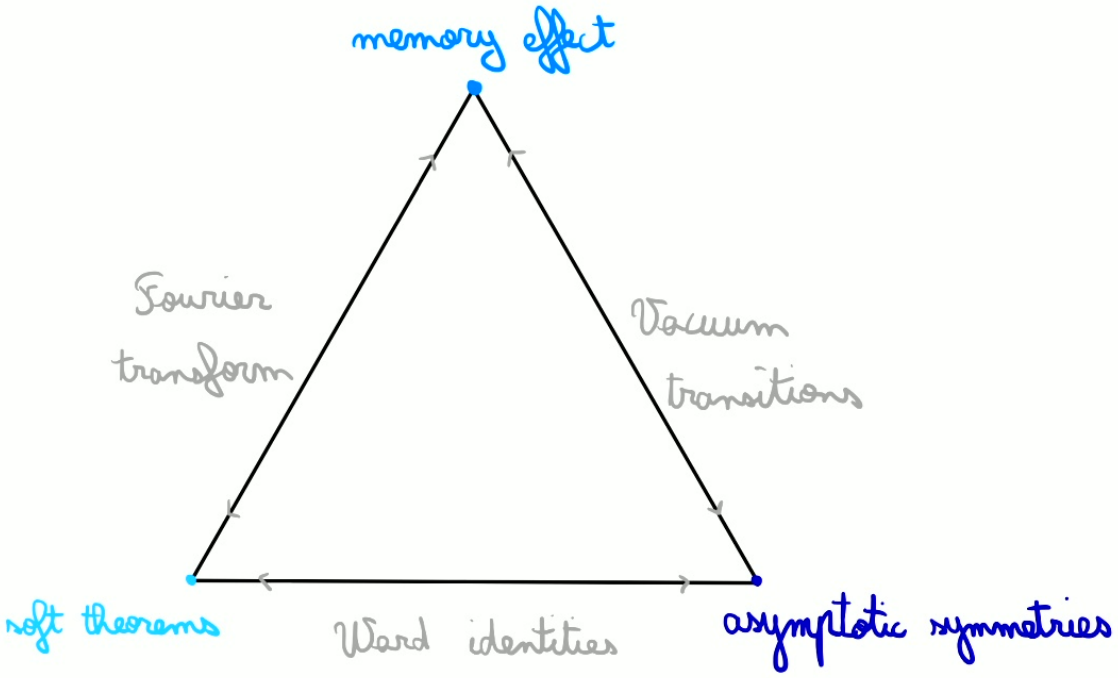
[8] [Pasterski '19, 1905.10052]

Full* Minkowski Asymptotic Symmetry Group (ASG)

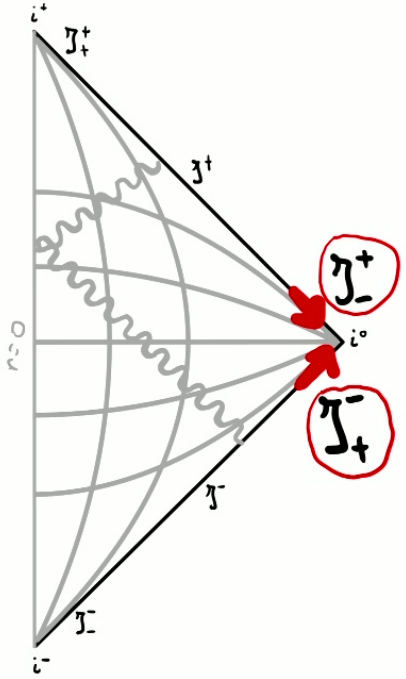


Soft theorems

First glance at infrared triangle



Antipodal matching



Liénard-Wiechert electric field $F \propto \frac{1}{r^2}$

$$\lim_{r\to\infty} r^2 F_{ru}(\hat{x})\Big|_{\mathcal{I}^+_-} = \lim_{r\to\infty} r^2 F_{rv}(-\hat{x})\Big|_{\mathcal{I}^-_+}$$

[9] [Strominger '18, Lectures on the Infrared Structure of Gravity and Gauge Theory]

Infinite number of conserved charges → Ward identities

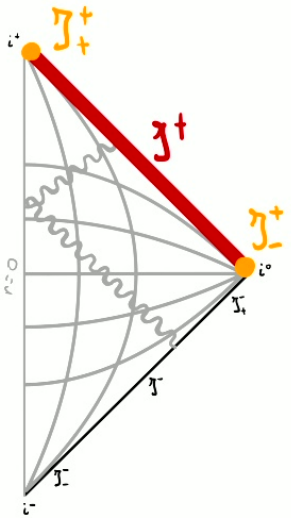
$$\lambda(z,\bar{z})\Big|_{\mathcal{I}^+_-} = \lambda(z,\bar{z})\Big|_{\mathcal{I}^-_+}$$

$$Q^+_\lambda = \frac{1}{e^2}\int_{\mathcal{I}^+_-} \lambda * F, \quad Q^-_\lambda = \frac{1}{e^2}\int_{\mathcal{I}^-_+} \lambda * F$$

$$\langle \text{out}|\, Q^+_\lambda S - S Q^-_\lambda \,|\text{in}\rangle = 0$$

[9] [Strominger '18, Lectures on the Infrared Structure of Gravity and Gauge Theory]

Stokes to volume integral gives soft photon term



$$Q^+_\lambda = \frac{1}{e^2}\int_{\mathcal{J}^+_-} \lambda * F$$

$$= \frac{1}{e^2}\int_{\mathcal{J}^+} d\lambda \wedge *F + \int_{\mathcal{J}^+} \lambda \wedge d * F + \frac{1}{e^2}\int_{\mathcal{J}^+_+} \lambda * F$$

$$= \underbrace{\frac{1}{e^2}\int_{\mathcal{J}^+} d\lambda \wedge *F}_{\text{soft photon}} + \underbrace{\int_{\mathcal{J}^+} \lambda * j}_{\text{matter term}}$$

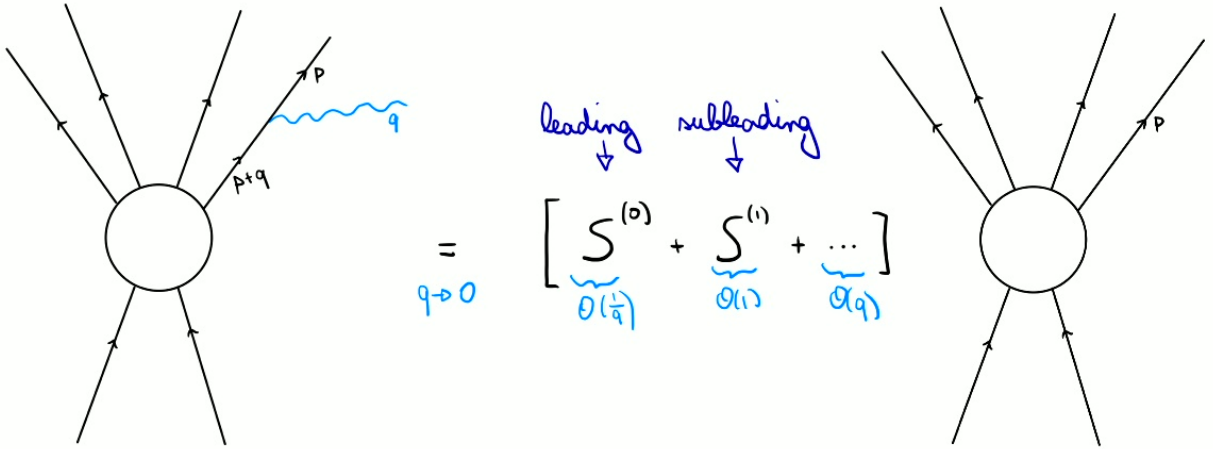
[9] [Strominger '18, Lectures on the Infrared Structure of Gravity and Gauge Theory]

What is a soft particle?

massless particle whose energy goes to 0

$$p = (\omega, \vec{p})\Big|_{\omega \to 0}$$

Scattering amplitude in soft limit



[10] [Weinberg '95, The Quantum Theory of Fields, chap 13]

Subleading soft theorem gave us superrotations

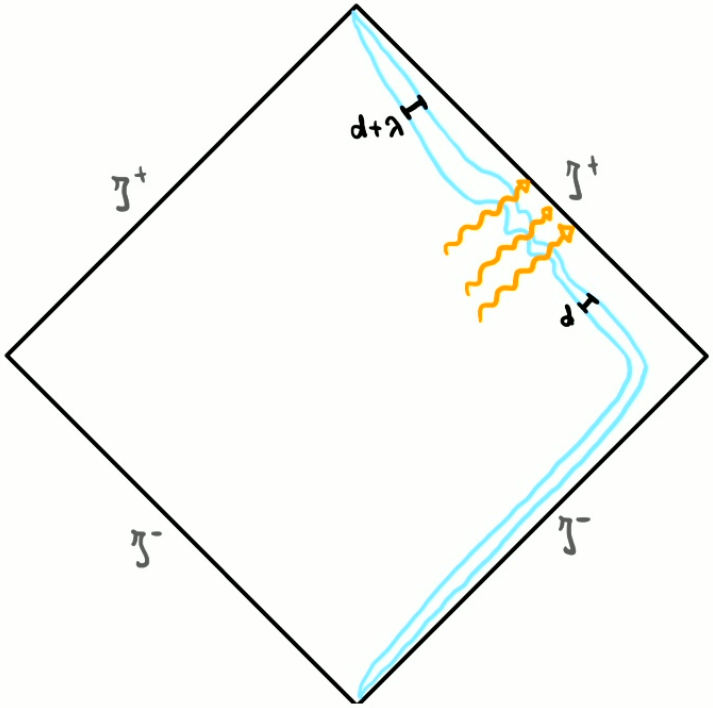
supertranslations $f^+(z,\bar{z})$ $\Rightarrow$ soft graviton theorem

$\downarrow$

superrotations $Y^+(z,\bar{z})$ $\Leftarrow$ subleading soft graviton theorem

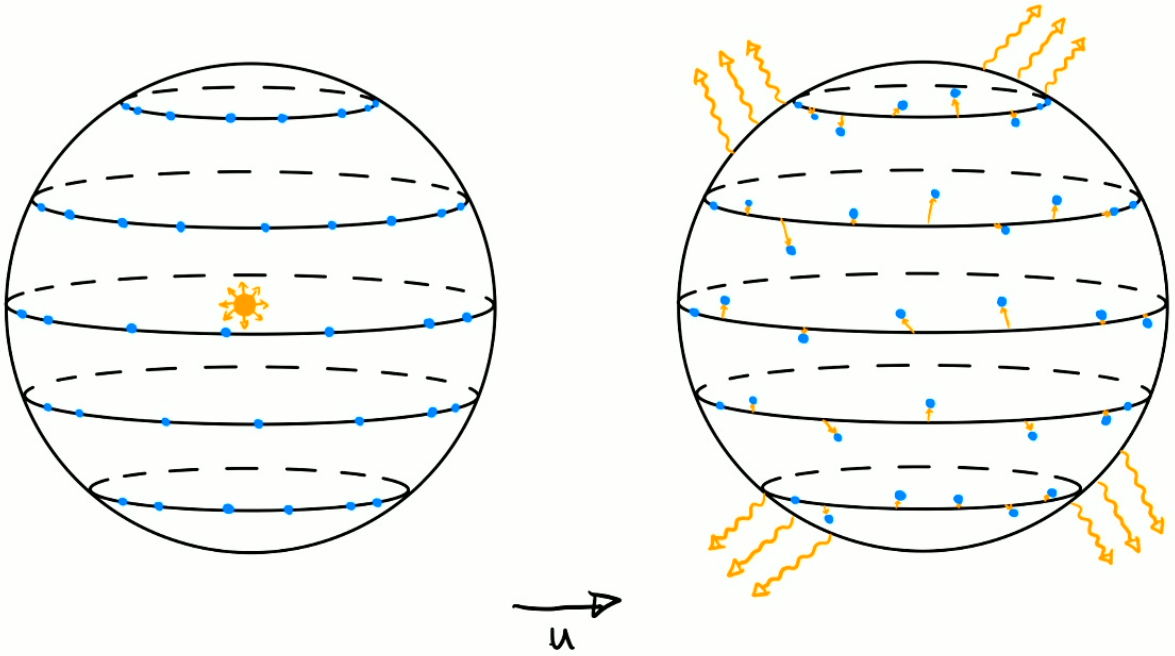
[8] [Pasterski '19, 1905.10052]

Gravitational memory effect $\Longleftrightarrow$ addition of soft graviton



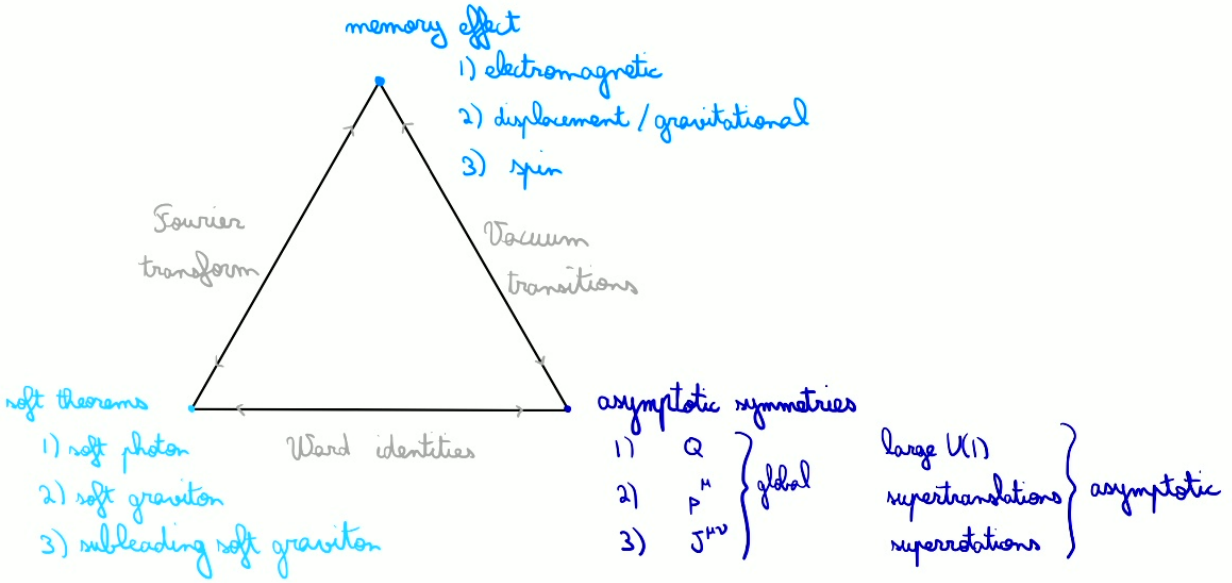
[10] [Strominger, Zhiboedov '14, 1411.5745]

Gravitational memory effect $\Longleftrightarrow$ supertranslation



[10] [Strominger, Zhiboedov '14, 1411.5745]

Infrared triangle with examples

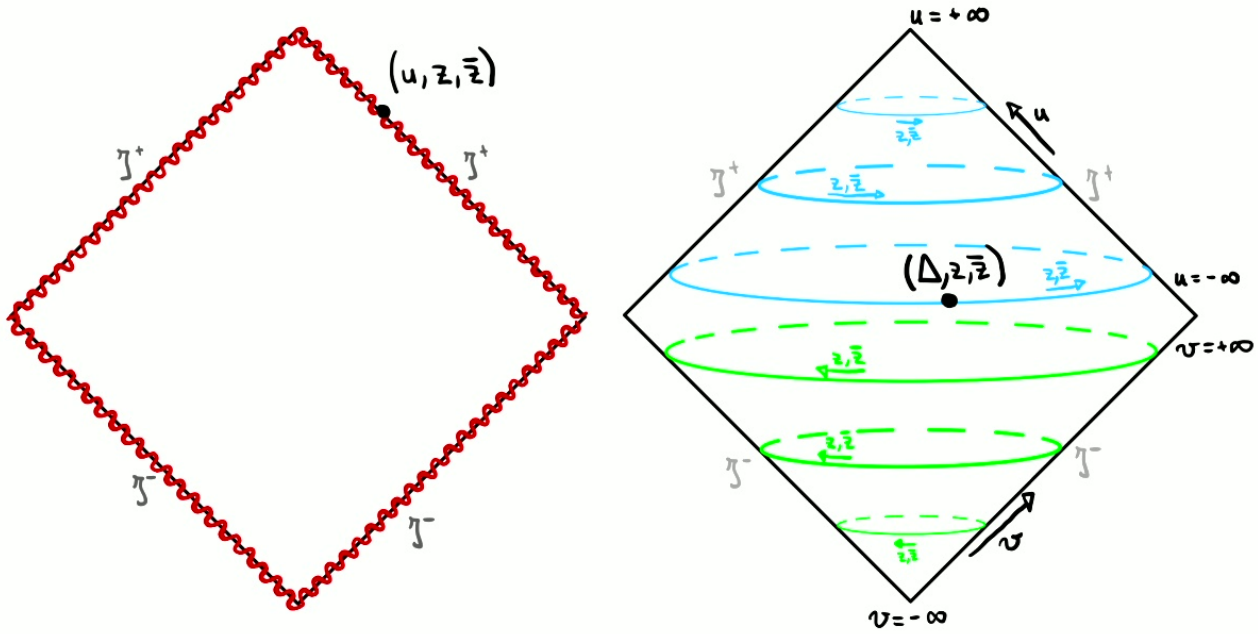


[7] [Pasterski '19, 1905.10052]

Insertion of soft graviton mode $\Longleftrightarrow$ 2d stress tensor

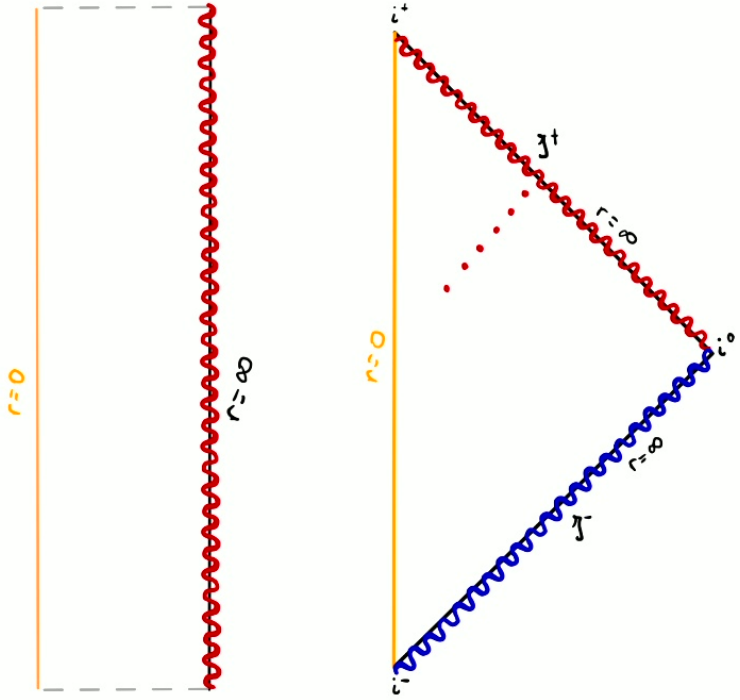
4d superrotations obey the same algebra as conformal transformations on CS^2

Codimension 1 vs. codimension 2



[11] [Ciambelli, Marteau, Petkou, Petropoulos, Siampos '18, 1802.06809]

Bulk reconstruction



Questions?

Quick Summary

- The grounds for holography should hold in any spacetime
- The boundary for Minkowski is null so massless particles can leak through
- Finding the symmetries of flat space is the first step in finding holographic dual
- Present goal is to reconstruct the flat space bulk from the celestial sphere dual

References

1. ['t Hooft '93, 9310026]
2. [Susskind '94, 9409089]
3. [Maldacena '98, 9711200]
4. [Raclariu '21, 2107.02075]
5. [Oblak '18, 1508.00920]
6. [Bondi, van der Burg, Metzner, Sachs '62, Gravitational waves in GR, vii.&viii.]
7. [He, Lysov, Mitra, Strominger '15, 1401.7026]
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