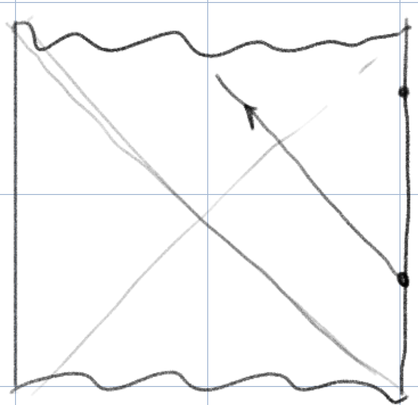
Comment on the Saad Wormhole

1. Maldacena's BH info paradox.

$$\langle O(t)\, O(0)\rangle_E = \sum_{n,m} |\langle n|O|m\rangle|^2\, e^{i(E_n - E_m)t}$$

$E_n, E_m \in \left(E - \frac{\Delta E}{2}, E + \frac{\Delta E}{2}\right)$. $\quad e^{S_E}$.

$$t > e^{S_E} \Rightarrow \langle OO\rangle \sim \sum_n |\langle n|O|n\rangle|^2 \sim e^{-S_E}$$



$e^{-i\omega t}$ $\quad \mathrm{Im}\,\omega \neq 0$.

quasinormal decay.

Q: how to get the Late time correction?

discreteness of spectrum.

2. Recent years progress. BH & Quantum Chaos.

prediction of 2pt based on RM Universality.

ETH: $|\langle n|\mathcal{O}|m\rangle|^2$ smooth in E_n, E_m.

rough idea. eigenstate of a chaotic system

is very nonlocal, no sensitive dependence on local observables

$$\Rightarrow \langle \mathcal{O}\mathcal{O}\rangle \sim |\langle E|\mathcal{O}|E\rangle|^2 \underbrace{\sum_{n,m} e^{i(E_n - E_m)t}}_{\substack{\shortparallel \\ Z(it)\, Z(-it)}}$$

Spectral form factor
"SFF"

$$SFF = \int dE\, dE' \langle \rho(E)\, \rho(E')\rangle\, e^{i(E-E')t}$$

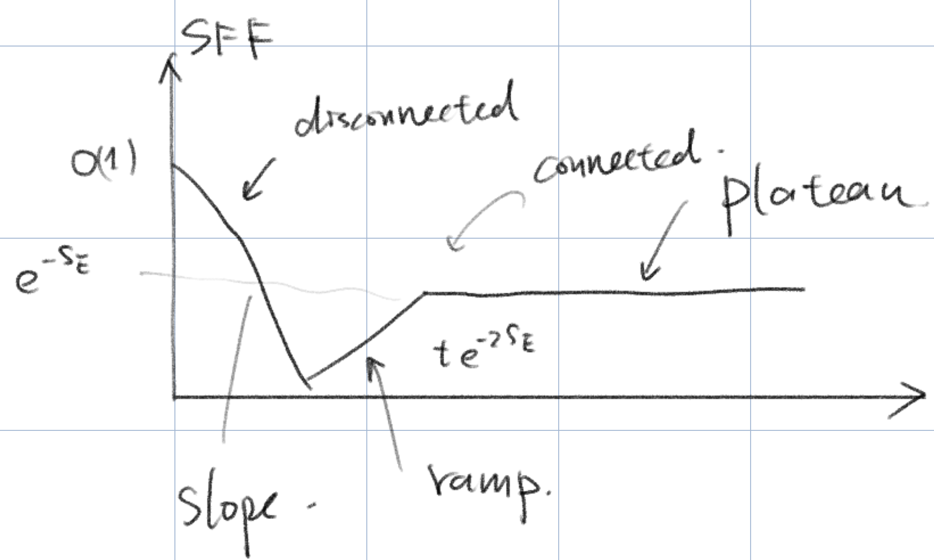
$$\langle \rho(E)\, \rho(E')\rangle_c \sim \delta(E-E')\, e^{S_E} - \left(\frac{\sin(\pi(E-E')e^{-S_E})}{\pi(E-E')}\right)^2$$

$$\mathrm{SFF} \sim \min(t, e^{S_E}) \times e^{-2S_E}.$$

ramp.

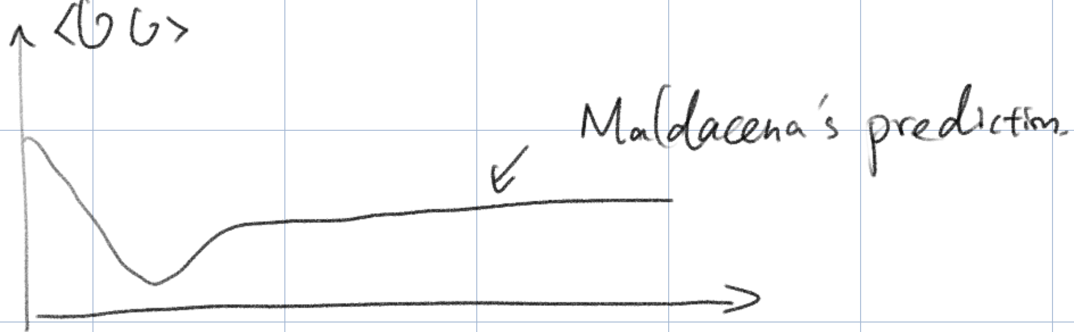
$$\int d\bar{E}\, d\omega \frac{1}{\omega^2} e^{i\omega T}$$

$$= \int d\bar{E}\, T = \Delta E\, T$$



For a generic chaotic system.

Similarly 2pt.



(More precisely. ETH ⇒

$$\langle n|O|m\rangle = G(E)\,\delta_{nm} + e^{-S_E/2} f(E,\omega)\, R_{nm}.$$

random number

$G(t)$

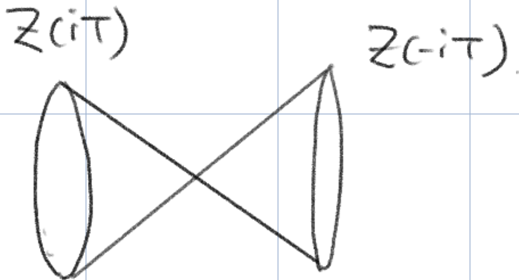
$$\sim \frac{1}{Z}\int d\omega\, e^{-S_E} |f(E,\omega)|^2 \frac{1}{\omega^2} e^{i\omega t} \sim |f(E,0)|^2 t e^{-2S_E})$$

Q: how to get ramp behavior of $G(t)$?

3. Progress in JT Gravity (Saad-Shenker-Stanford, Saad)

In two dimensional AdS BHs, progress has been made by SSS & Saad. (geometry given by Riemann surfaces).

SSS: SFF ramp. comes from wormhole doublecone



Saad 2pt. ramp comes from HD

work out the quantum BU emission operator

We will show how to generalize them to higher dims.

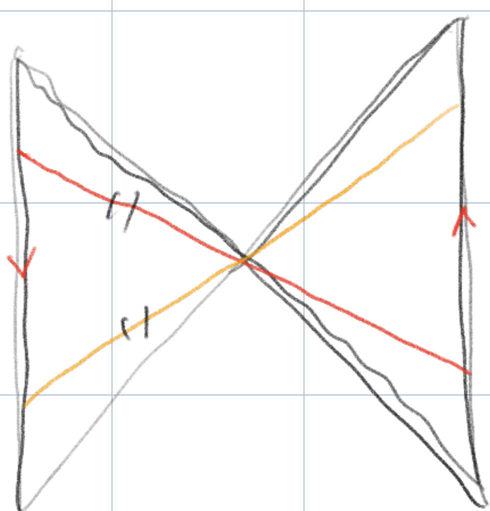
II SFF. doublecone has higher dim generalization

when it was introduced by SSS. recent more explicit discussions see Chen-Ivo-Maldacena.

AdS Schwarzchild BH

$$ds^2 = -f(r)\,dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega_2$$

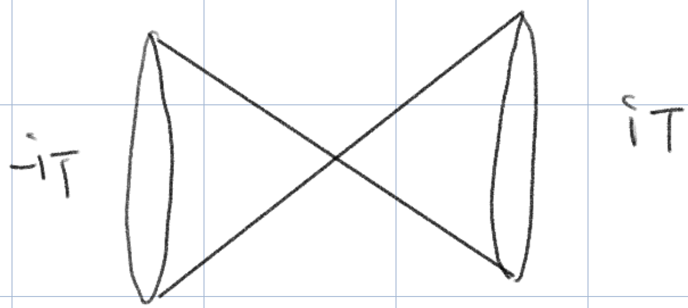
$$f(r) = 1 + r^2 - \frac{2M}{r}.$$



Boost Symmetry

K

$t \sim t + T.$ <u>double cone</u>



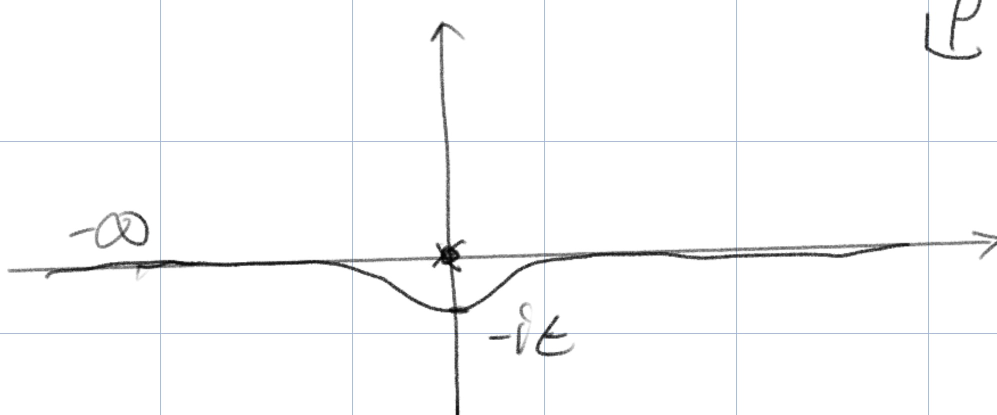
$\sim Z(iT)\, Z(-iT)$.

near the horizon. fixed point

double cone requires a deformation.

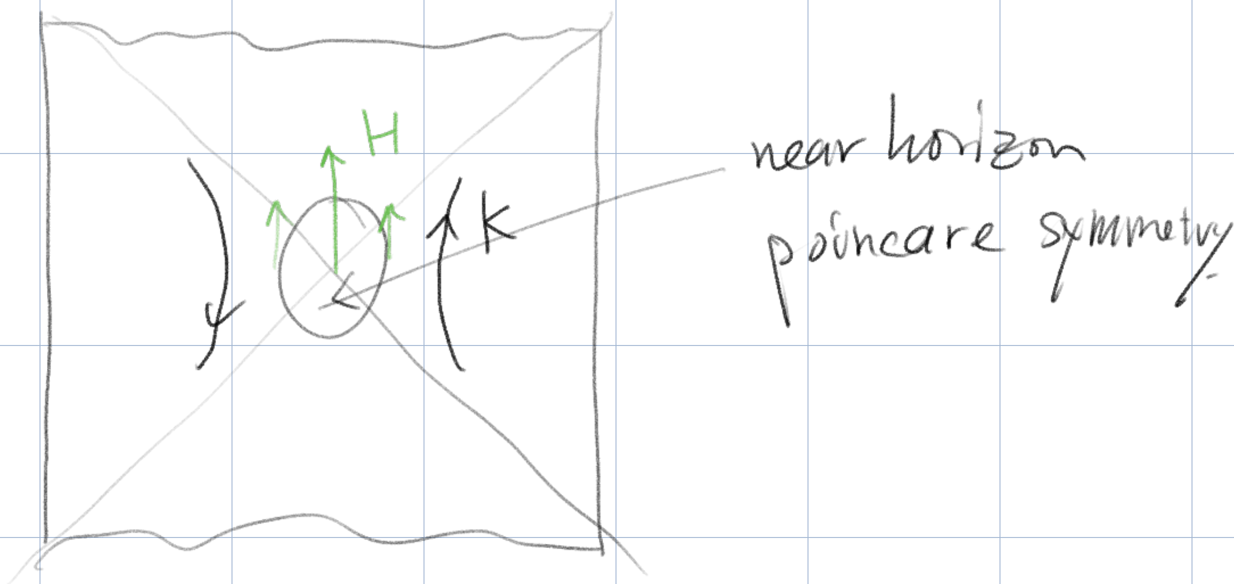
$r \sim r_h + \rho^2$. $\quad \rho$: rindler radius.

$ds^2 \sim -\rho^2 dt^2 + d\rho^2 + r_h^2 \cdots$



$\Rightarrow \quad ds^2 = \underline{\epsilon^2 dt^2} + d\rho^2$.

near horizon ∂_t. global time translation.



$$\tilde{K} = K - i\epsilon H$$

notice H is a two sided operator,

$\Rightarrow$ $\tilde{K}$ is a two sided operator,

$\Rightarrow$ double cone couples two sides.

$$\underline{\overline{\mathrm{Tr}}\, e^{-i\tilde{K}T}}$$

$i\epsilon$ description can be thought of as averaging over near horizon degrees.

$\Rightarrow$ spectrum $\tilde{K}$ is given by QNMs.

(SSS, CIM)

$\Rightarrow$ Matter fluctuations decays at late time.

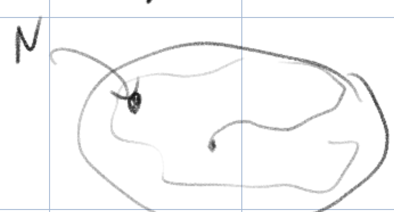
$$Z_m^{(DC)} \sim 1 + n e^{-i\omega_{QNM} T} \to 1$$

$$T \geq \frac{\log n}{\mathrm{Im}(\omega_{min})}$$ ← thouless time.

generically given by hydrodynamic modes. [Winer-Swingle]

$$T_{\text{thouless}} \sim V^{\#}$$

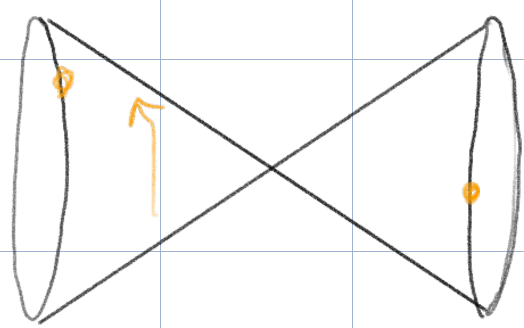
matches w/ classical intuition.



thouless time is the time particle diffuses over the whole space.

Importantly independent of N. strong chaos

Zero modes



twist s.

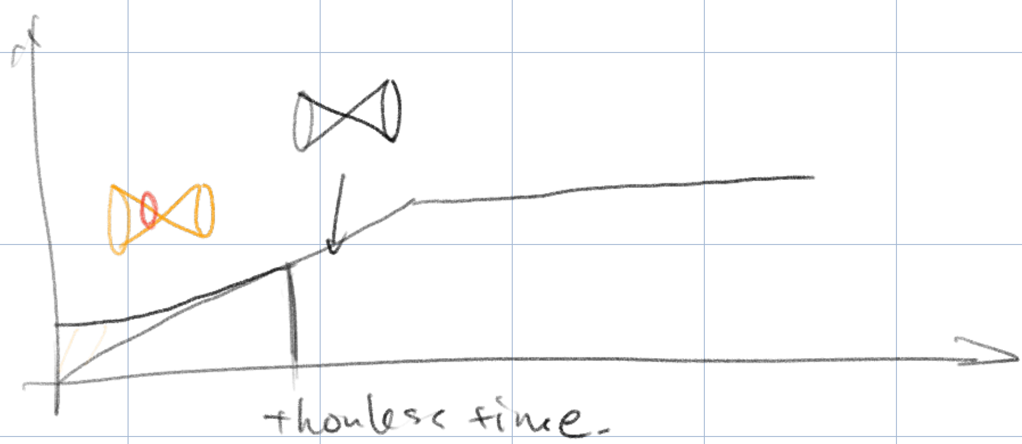
$s \sim (0, T)$

action. vanishes. only bdy terms

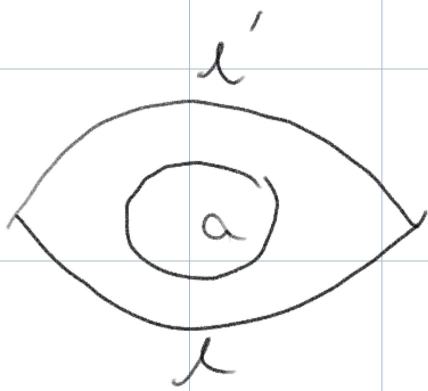
$iTE - iTE = 0$.

$$S = 0.$$

$$\mathrm{SFF} = \int ds\, dE \Rightarrow T \Delta E$$ linear ramp



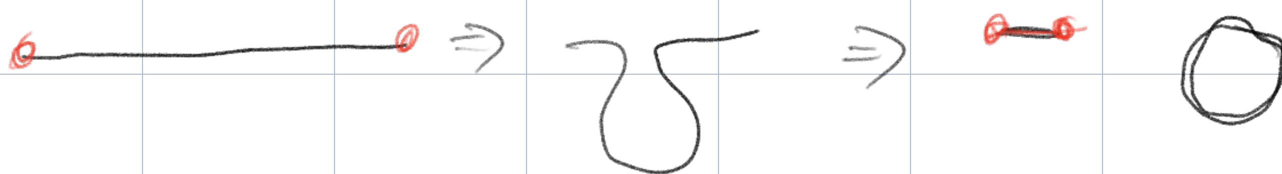
II. Saad Wormhole.



$l' + a \approx l$

$a \sim l \Rightarrow l'$ small

$\Rightarrow$ shortening picture.



Hard to work out the BU emission operator in higher dimensions.

Even quantum wavefunctional unknown.

Good thing: Saad Wormhole is a classical geometry. ⇒ directly construct the classical geometry in higher dimension.

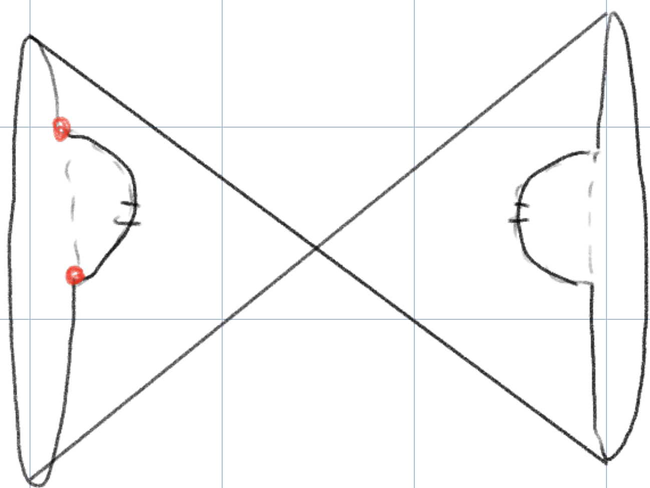
$$SFF = \left|\langle TFD(t) | TFD(0)\rangle\right|^2.$$

$$\Rightarrow \rho_t \supset t\, \rho_0\, e^{-2S}.$$

how to get the ρ_0 component?

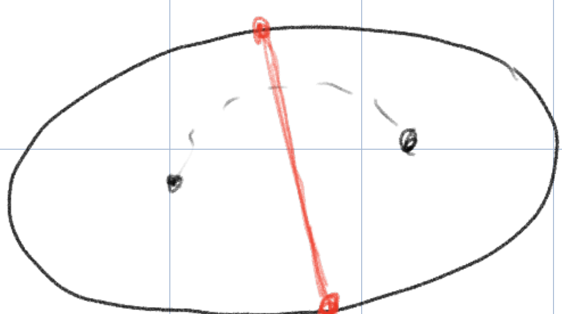
Classical geometry of ρ_0.

$$e^{-ikT} \sim e^{-ikT+\pi k - \pi k}$$

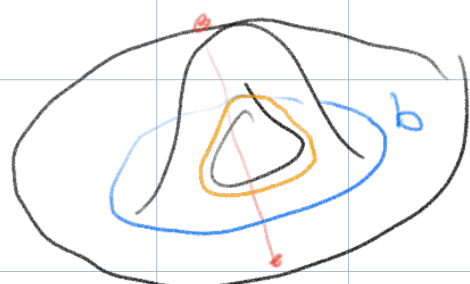


insert two point function & glue

$$1 \ll \Delta \ll \frac{1}{G_N} \ll T$$



Saad WH



Comments:

1. action

e^{-S_E} suppressed

2. twist $S \gg t_{thouless}$.

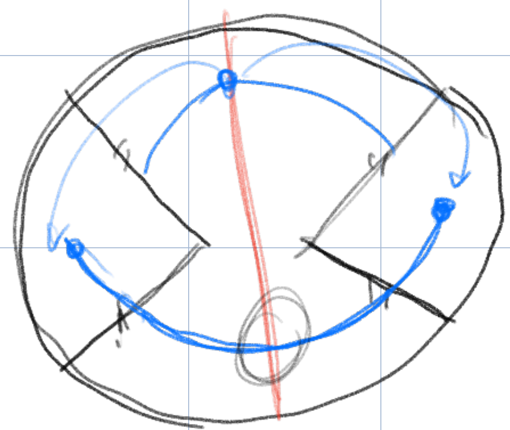
$$\int ds \sim T - 2T_{thouless} \approx T$$

$$T e^{-S_E}$$

3. potential issue. other small cycles

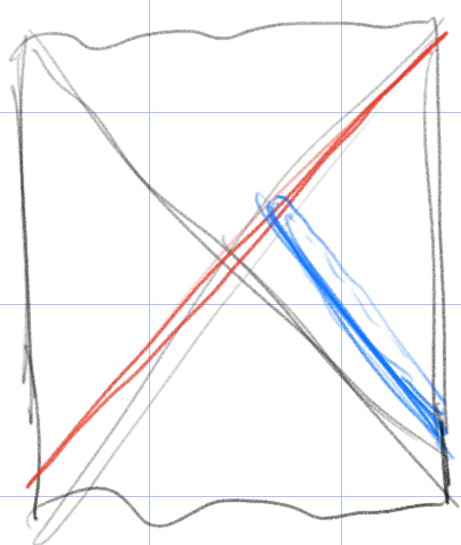
b. stablized by two pt.

can be studied using developing map



OTOC high energy collision.

$b \sim 2T \gg 1 \qquad G_N e^T \gg 1$



In the absence of operator insertion, b small. X

$\Rightarrow$ Saad WH doesn't contribute to partition function.

4. Can cut out more Lorentzian regions.

smaller 2pt function.

$$\Rightarrow \int dt \langle \mathcal{O}(t)\mathcal{O}(0)\rangle \times \text{SFF}$$

matches w/ bdy calculation.

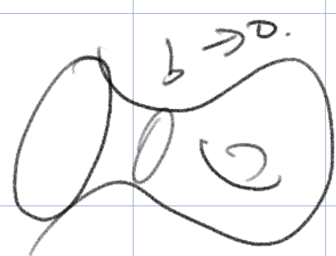
General Comments.

1. RMU vs RMT.

JT RMT dual. special

two types of WHs.

1. small WHs.

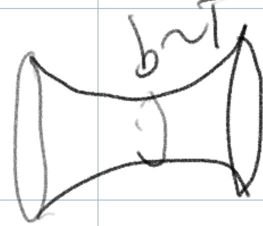


RMT

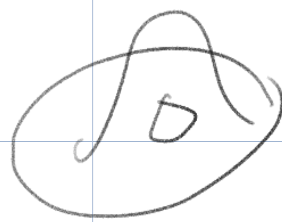
$$\int db\, e^{-b^2/\beta} V_n(b) \to b=0.$$

2. Large WHs.

1. double cone SSS

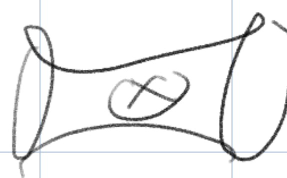


2. Saad WH. Saad

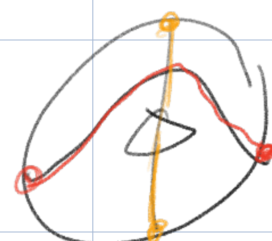


cycles >> 1.

3. double cone w/ crosscap GOE SSSY

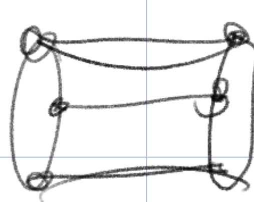


4. Late-time OTOC SSY



5. replica WH PSSY

6. correlators Saad Stanford



"periodic orbits" : quantum chaotic WHs.

2. Chaos & near horizon poincare symmetry.

1. double cone $\quad K, \underbrace{H = P^+ + P^-}$

2. Stablize Saad WH. $\quad$ shockwave.

P^+, P^-

QCWH seems been build out of poincare algebra. universal

What's more?

Can we translate RMU into the universality of Rindler horizon?