A BMS-invariant free scalar model

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Pengxiang Hao, WS, Xianjin Xie and Yuan Zhong, 2111.04701

& earlier work with Luis Apolo, Hongliang Jiang, Qiang Wen, Jianfei Xu and Yuan Zhong

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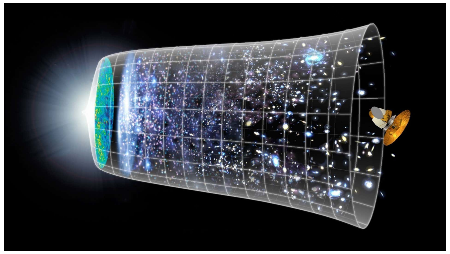
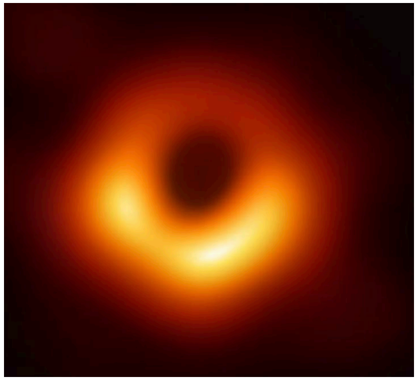
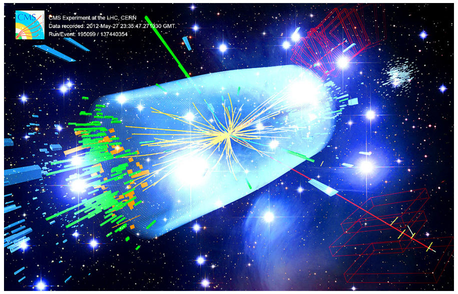
The study of the AdS/CFT correspondence has been very fruitful. But more steps are necessary to understand our real world.

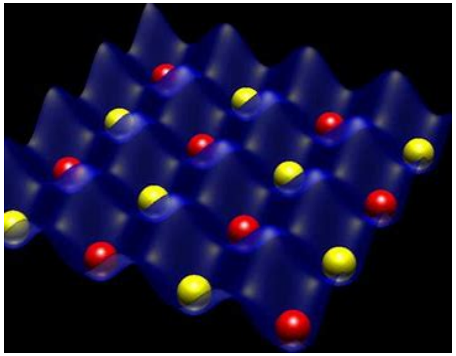
Non-AdS geometries





Non-CFT quantum systems





Question:

Will holography still work for asymptotically flat spacetime, and if so, how does it work?

Top down approach:

-BFSS matrix model

-TsT / $T\bar{T}$ deformation

- ⋯

Bottom up approach:

-glue AdS to flat space

-flat/celestrial CFT in 4d

-flat/BMSFT in 3d

- ⋯

- ➢The setup: flat holography in 3d
- Holographic entanglement entropy
- A free scalar model of BMSFT

Warmup: AdS_3 */* CFT_2 *from bottom up approach*

Einstein gravity w/ negative c.c & the Brown-Henneaux boundary conditions	CFT_2
Global AdS_3	vacuum on the cylinder
Poincare AdS_3	vacuum on the plane
Isometry group SL(2,R)x SL(2,R)	*symmetry for the vacuum SL(2,R)x SL(2,R)*
Asymptotic symmetry Virasoro *x* Virasoro	2d conformal symmetry Virasoro *x* Virasoro
Entropy for BTZ black holes	Cardy formula
HHRT formula	Entanglement entropy

[Bondi, van der Burg, Metzner, Sachs 62']
[Barnich-Compere 06', Bagchi-Gopakumar 09', Barnich-Troessaert, Bagchi 10']

Flat holography for 3d Einstein gravity

From $AdS_3 : l = \frac{1}{\epsilon} \to \infty$

Asymptotic flat solutions of pure Einstein gravity in Bondi gauge

$$\mathrm{ds}^2 = \mathrm{P}(\phi)du^2 - 2dudr + \left[J[\phi] + u\partial_\phi \mathrm{P}(\phi)\right]dud\phi + r^2 d\phi^2,$$

← Bananos solutions

$$\phi \sim \phi + 2\pi$$

Zero mode solutions: $ds^2 = Mdu^2 - 2dudr + Jdud\phi + r^2 d\phi^2$

- $M = -1,\ J = 0$ global Minkovski spacetime, with isometry generators: $L_1, L_0, L_{-1}, M_1, M_0, M_{-1}$ *global AdS*
- $M > 0$, Flat space cosmological solutions(FSC) with a Cauchy horizon *BTZ with the inner horizon*
- $M < 0$, conical defects

Alternative perspective: flat limit of AdS_3 gravity

The asymptotic symmetry generators includes superroations L_m and supertranslations M_n.

BMS_3 algebra with central extension,

$$[L_n, L_m] = (n-m)L_{n+m} + \frac{c_L}{12}(n^3-n)\delta_{n+m,0}$$
$$[L_n, M_m] = (n-m)M_{n+m} + \frac{c_M}{12}(n^3-n)$$
$$[M_n, M_m] = 0$$

For Einstein gravity, the gravitational anomaly

$c_L = 0, \quad but \quad c_M = \frac{3}{G}$

For topologically massive gravity $c_L \neq 0$

$c^+ - c^- \to c_L, \qquad c^+ + c^- \to \ell\, c_M$

Asymptotic symmetry analysis suggests a holographic relation between the following theories:

- Three dimensional Einstein gravity with asymptotic flat boundary conditions imposed at null infinity
- Two dimensional quantum field theories with BMS invariance (BMSFT)

BMSFT: field theory invariant under BMS transformations

$$\tilde{\sigma} = f(\sigma), \;\; \tilde{\tau} = f'(\sigma)\tau + g(\sigma), \qquad\qquad \sigma \sim \sigma + 2\pi$$

From cylinder to plane: $x = e^{i\sigma}, \; y = i\, e^{in\sigma}\, \tau$

Generators n the plane:

$$l_n = -x^{n+1}\partial_x - (n+1)yx^n\partial_y$$
$$m_m = -x^{n+1}\partial_y$$

States fall into representations of the centrally extended BMS algebra

$$[L_n, L_m] = (n-m)L_{n+m} + \frac{c_L}{12}(n^3 - n)\delta_{n+m,0}$$
$$[L_n, M_m] = (n-m)M_{n+m} + \frac{c_M}{12}(n^3 - n)$$
$$[M_n, M_m] = 0$$

BMSFT as the UR (ultra relativistic) limit of CFT_2

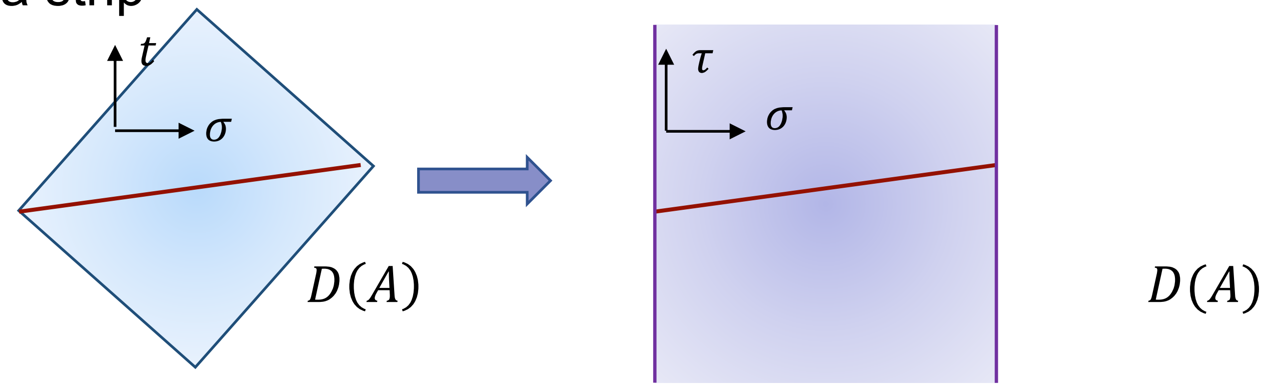
consistent with the bulk $\epsilon \propto \frac{1}{l}$

From CFT_2 : ultra relativistic limit on the cylinder $t \to \epsilon\,\tau, \quad \sigma \to \sigma$

$$L_n^+ - L_{-n}^- \to L_n, \qquad L_n^+ + L_{-n}^- \to \frac{M_n}{\epsilon},$$

$$c^+ - c^- \to c_L, \qquad c^+ + c^- \to \frac{c_M}{\epsilon}$$

Effectively the speed of light is going to zero, and the causal diamond becomes a strip



Galilean conformal algebra (GCA): non-relativistic limit $t \to t, \quad \sigma \to \epsilon\,\sigma$

[Duval-Horvathy 09', Martelli-Tachikawa, 09']

BMS algebra is isomorphic to GCA, but lots of properties are different.

- Torus partition function for BMSFT is modular invariant.

$$(\tau,\sigma) \sim (\tau + i\bar{a}, \sigma - ia) \sim \left(\tau + i\bar{b}, \sigma - ib\right)$$

- `Cardy' formula for BMSFT

Barnich
Bagchi-Detournay-Fareghbal-Simón

$$S_{\bar{b}|b}(\bar{a}|a) = -\frac{\pi^2}{3}\left(c_{\rm L}\frac{b}{a} + c_{\rm M}\frac{(\bar{a}b - a\bar{b})}{a^2}\right).$$

reproduces the entropy of FSC

- Torus 1pf vs asymptotic structure constant

Kraus-Moloney
WS-Xu
Bagchi-Nandi-Saha-Zodinmawia

- Conformal bootstrap

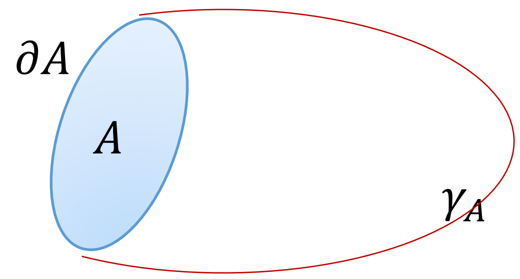
Bagchi-Gary, 16'
Chen-Hao-Liu-Yu, 20'

$flat/BMSFT$ from bottom up approach

3d Einstein gravity in asy. flat spacetime	$BMSFT$
Global $Minkovski$	vacuum on the cylinder
Poincare	vacuum on the plane
Isometry group *Poincare* $L_n, M_n, n = 0, \pm 1$	*symmetry for the vacuum* $L_n, M_n, n = 0, \pm 1$
Asymptotic symmetry Generated by L_n, M_n	BMS symmetry Generated by L_n, M_n
Entropy for FSC black holes	Cardy formula
Holographic entanglement entropy	Entanglement entropy

Holographic entanglement entropy in AdS/CFT

Ryu-Takayanagi,
Hubeny-Rangamani-Takayanagi



$$S_A = \min \frac{\mathrm{Area}(\gamma_A)}{4G}$$

γ_A: co-dimension 2 extremal surface homologous to ∂A

Well established in AdS/CFT, for Einstein Gravity

- Rindler method: *Casini-Huerta-Myers (CHM)*
- Generalized gravitational entropy
  Lewkowyzy-Madalcena, Dong-Lewkowyzy-Rangamani

Question: what is the holographic entanglement entropy in holographic dualities for non-AdS spacetimes?

Our approach:
use the “proof” to “derive” the bulk picture

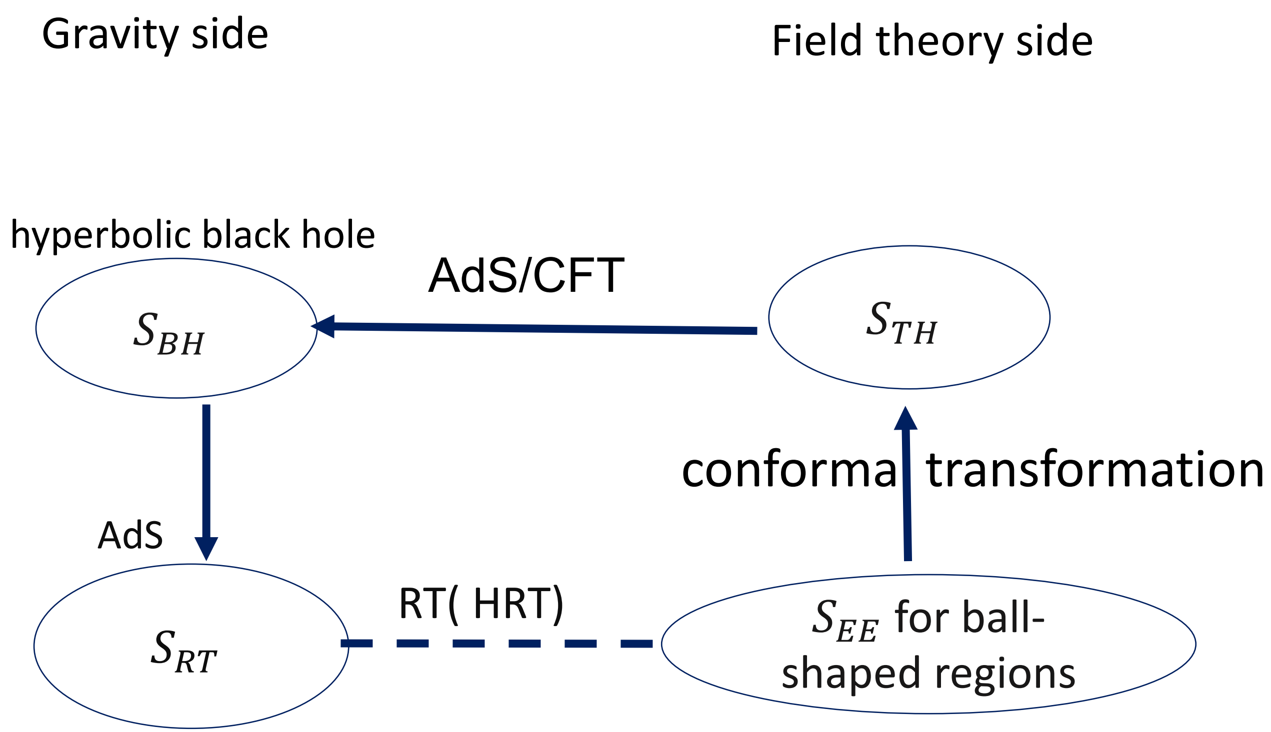
- Assumptions: flat holography exists.

Asymptotic symmetry in gravity =symmetry of the dual field theory=BMS

- A new geometric picture: the swing surface

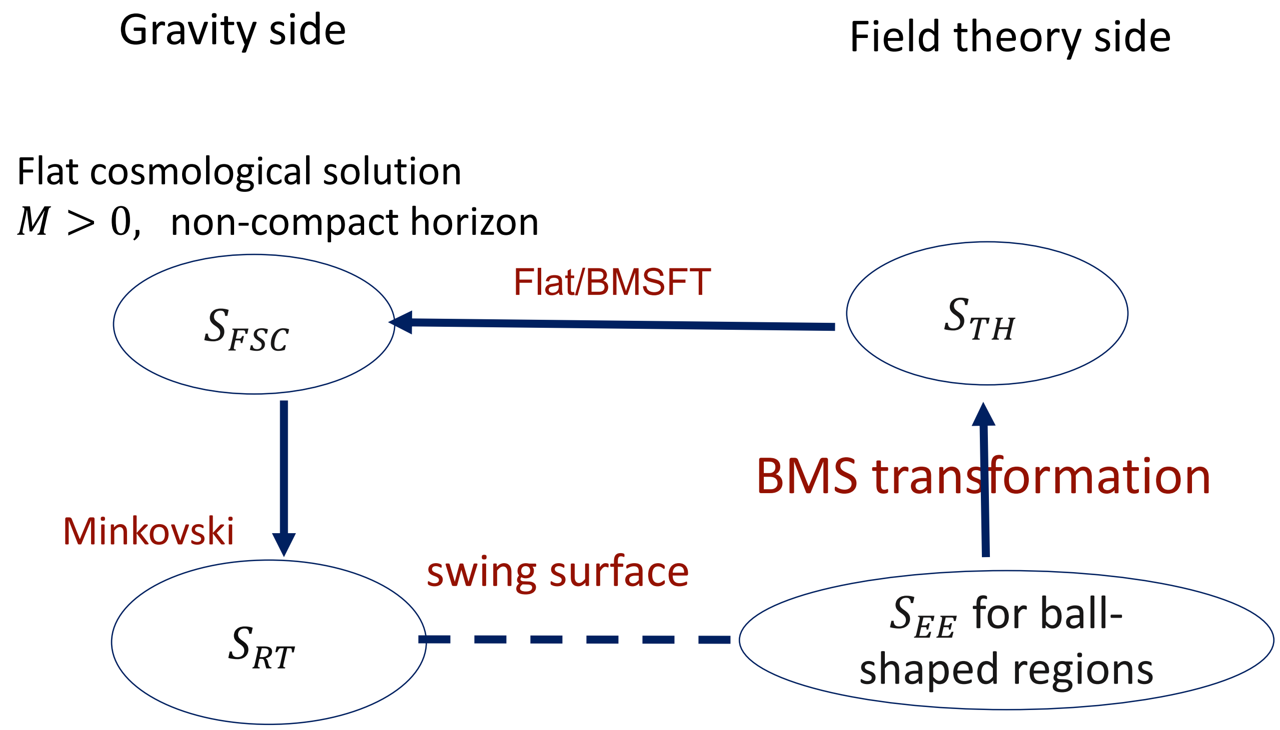
The Rindler method in AdS/CFT :
derivation of RT for ball-shaped subregions

Casini-Huerta-Myers



The generalized Rindler method in non-AdS holography :
derivation for ball-shaped subregions

Castro-Hofman-Iqbal
WS-Wen-Xu
Jiang-WS-Wen



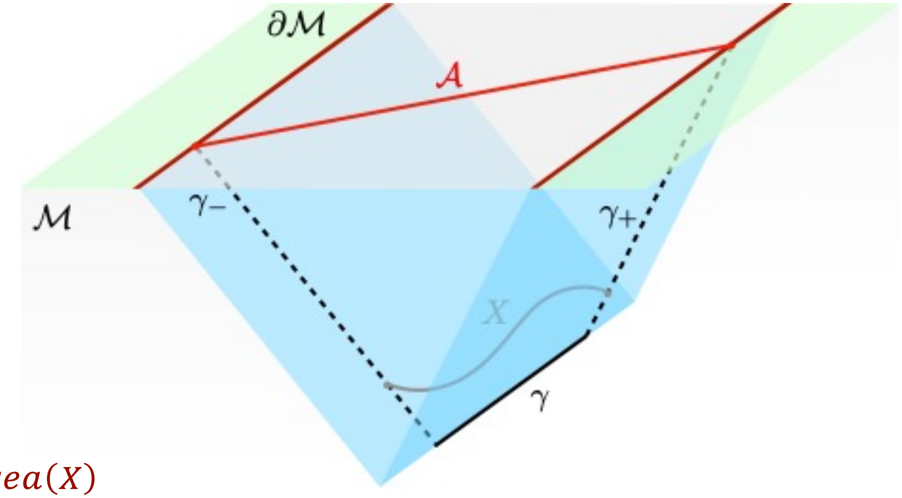
WS-Wen-Xu, 17'
Jiang-WS-Wen, 17'
Apolo-Jiang-WS-Zhong 20'
Apolo-Jiang-WS-Zhong, 20'

The new geometric picture:

holographic entanglement entropy is given by an extremal swing surface

boundary

bulk



$$S_A = \frac{Area(\gamma_A)}{4G} = \min_{X \sim A} \frac{Area(X)}{4G}$$

$swing\ surface$: $\gamma_A = \gamma_+ \cup \gamma_- \cup \gamma$

ropes $\gamma_\pm$: null geodesics emanating from points in ∂A, along the modular flow direction

bench γ: extremal surface between γ_+ and γ_-

Consistency checks and related developments

Pure field theory calculation:
- Replica trick: 2pf of twist operators *Bagchi-Basu-Grumiller-Riegler*
- Generalized Rindler method: $S_{EE} \to S_{TH} \to S_{Generalized\ Cardy}$ *Jiang−WS−Wen*

Holographic calculation:
- Wilson lines in Chern-Simons formalism *Basu-Riegler*
- Rindler method *Jiang-WS-Wen*
- Generalized gravitational entropy argument *Apolo-Jiang-WS-Zhong 20'*

Flat limit from AdS_3 /Wigner contraction from CFT

Geodesic Witten diagrams *Hijano-Rabideau, Hijano*

Quantum energy conditions *Grumiller-Praekh-Riegler*

Entanglement 1st law vs the Einstein equation *Godet-Marteau, Fareghbal-Shalamzari*

Modular Hamiltonian *wen 18', Apolo-Jiang-WS-Zhong 20'*

- ✓ The setup: flat holography in 3d
- ✓ Holographic entanglement entropy
- ➢ A free scalar model of BMSFT

BMSFT: field theory invariant under BMS transformations

$$\tilde{\sigma} = f(\sigma), \;\; \tilde{\tau} = f'(\sigma)\tau + g(\sigma), \qquad\qquad \sigma \sim \sigma + 2\pi$$

From cylinder to plane: $x = e^{i\sigma}, \; y = i\, e^{in\sigma}\, \tau$

Generators n the plane:

$$l_n = -x^{n+1}\partial_x - (n+1)yx^n\partial_y$$

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States fall into representations of the centrally extended BMS algebra

$$[L_n, L_m] = (n-m)L_{n+m} + \frac{c_L}{12}(n^3 - n)\delta_{n+m,0}$$

$$[L_n, M_m] = (n-m)M_{n+m} + \frac{c_M}{12}(n^3 - n)$$

$$[M_n, M_m] = 0$$

A free scalar model of BMSFT

Hao-WS-Xie-Zhong, 21'

The action on the cylinder $S = \frac{1}{4\pi}\int d\tau\, d\sigma\ \ (\partial_\tau \phi)^2$

is invariant under the BMS tranformations

$$\sigma \to \sigma' = \sigma + \varepsilon(\sigma)$$
$$\tau \to \tau' = \tau + \varepsilon'(\sigma)\tau + \tilde{\varepsilon}(\sigma).$$

The transformation rule for the scalar:

$$\delta_{\varepsilon(\sigma)}\phi = -\varepsilon(\sigma)\partial_\sigma\phi - \varepsilon(\sigma)'\tau\partial_\tau\phi,$$
$$\delta_{\tilde{\varepsilon}(\sigma)}\phi = -\tilde{\varepsilon}(\sigma)\partial_\tau\phi.$$

The Neother currents

$$2\pi \boldsymbol{j}_{\varepsilon(\sigma)} = \Big(\varepsilon(\sigma)T + \varepsilon'(\sigma)\tau M\Big)d\sigma + \varepsilon(\sigma)M d\tau,$$

$$2\pi \boldsymbol{j}_{\tilde{\varepsilon}(\sigma)} = \Big(\tilde{\varepsilon}(\sigma)M\Big)d\sigma.$$

$$T = -\partial_\sigma\phi\partial_\tau\phi$$

$$M = -\frac{1}{2}\partial_\tau\phi\partial_\tau\phi.$$

Conservation laws: $d\boldsymbol{j}_{\varepsilon(\sigma)} = d\boldsymbol{j}_{\tilde{\varepsilon}(\sigma)} = 0,$

The classical Neother charges

$$Q_{\epsilon_n} \Leftrightarrow L_n$$

$$Q_{\tilde{\epsilon}_n} \Leftrightarrow M_n$$

form BMS algebra under Possion bracket with vanishing classical central charges.

Hao-WS-Xie-Zhong, 21’

BMS free scalar theory

The action on the cylinder is $S = \frac{1}{4\pi} \int d\sigma d\tau (\partial_\tau \phi)^2.$

The equation of motion $\partial_\tau^2 \phi = 0.$

The classical solution to the equation of motion is given by

$$\phi(\sigma,\tau) = \sum_{n=-\infty}^{\infty} e^{-i\sigma n} \left(A_n + i\tau B_n\right)$$

The reality condition then implies the adjoint relation

$$A_n^\dagger = A_{-n}, \quad B_n^\dagger = -B_{-n}$$

- This model is a building block of the string worldsheet theory at the tensionless limit

  See e. g. Bagchi 13’, Bagchi- Banerjee-Chakrabortty 20’
- It also appears as the $\sqrt{T\bar{T}}$ deformation of CFT_2

  Rodriguez-Tempo-Troncoso 21’

From cylinder to plane: $x = e^{i\sigma}\,,\ y = i\,e^{in\sigma}\,\tau$

BMS free scalar theory

The action on the plane is $S = \frac{1}{4\pi}\int dydx(\partial_y\phi)^2.$

The equation of motion $\partial_y^2\phi = 0.$

The classical solution to the equation of motion is given by

$$\phi(\sigma,\tau) = \sum_{n=-\infty}^{\infty} x^{-n}\left(A_n + iy/xB_n\right)$$

The reality condition then implies the adjoint relation

$$A_n^\dagger = A_{-n}, \quad B_n^\dagger = -B_{-n}$$

- The reality condition is inherited from the cylinder
- Canonical quantization on the cylinder ⇔ radial quantization on the plane
- State-operator correspondence can be set up by a careful prescription of analytic continuation.

Canonical quantization

After canonical quantization, we have the commutation relations

$$[A_n, B_m] = \delta_{n+m,0}, \quad [A_n, A_m] = [B_n, B_m] = 0$$

Stress tensors are given by

$$T(x, y) = - : \partial_x \phi \partial_y \phi :, \quad M(x) = -\frac{1}{2} : \partial_y \phi \partial_y \phi :,$$

The conserved charges on the plane

$$L_n = \frac{1}{2\pi i} \oint \big((n+1) x^n y M + x^{n+1} T \big) dx, \quad M_n = \frac{1}{2\pi i} \oint dx x^{n+1} M.$$

generate the BMS transformations

$$l_n = -x^{n+1} \partial_x - (n+1) y x^n \partial_y, \quad m_n = -x^{n+1} \partial_y.$$

The vacuum

For CFT_2, the vacuum is invariant under $SL(2,R)\times SL(2,R)$

For BMSFT, the vacuum is invariant under th Poincar'e subgroup

$L_{\pm 1,\,0}|0\rangle = M_{\pm 1,\,0}|0\rangle = 0$

Option I: the highest weight vacuum $A_n|0\rangle = 0,\ n>0,\ B_m|0\rangle = 0,\ m\geq 0$

$M_n|0\rangle = 0, \quad L_n|0\rangle = 0, n\geq -1.$

BMS algebra with $c_L = 2,\ c_M = 0.$

Option II: the induced vacuum $B_n|0_I\rangle = 0,\ \forall n\in Z.$

$$L_0|0_I\rangle = M_n|0_I\rangle = 0, \qquad \forall n\in\mathbb{Z}.$$

Bagchi-Gopakumar-Mandal-Miwa 09'

Highest weight representation

Singlet: L_0 and M_0 can be diagonalized

Highest weight operator at the origin of the plane

$$[L_0, O] = \Delta O, \qquad [M_0, O] = \xi O.$$ Δ: conformal weight , ξ: boost charge

$$[L_n, O] = 0, \quad [M_n, O] = 0, \quad n > 0.$$

Local operators obtained from $O(x,y) = UO(0,0)U^{-1}.$

Subtleties:

1. non-unitarity
2. the action of L_0 and M_0 on the descendant operators are not simultaneously diagonal

The appearance of multiplets in descendants is a generic feature of BMS algebra.

Highest weight representation: multiplet

Chen-Hao-Liu-Yu, 20'
Hao-WS-Xie-Zhong, 21'

The action of M_0 is block diagonal

$$[L_0, O_a] = \Delta O_a, \qquad [M_0, O_a] = (\boldsymbol{\xi} O)_a, \quad a = 0, \cdots r-1$$

$$[L_n, O_a] = 0, \quad [M_n, O_a] = 0, \quad n > 0,$$

where O_a denotes the a-th component of the multiplet $\boldsymbol{O}$,

$\boldsymbol{\xi}$ is a Jordon cell with rank r ,

$$\boldsymbol{\xi} = \begin{pmatrix} \xi & & & \\ 1 & \xi & & \\ & \ddots & \ddots & \\ & & 1 & \xi \end{pmatrix}_{r\times r} .$$

r is called the rank of the multiplet.
When $r = 1$ we get back the singlet.

The free scalar model

Hao-WS-Xie-Zhong, 21'

Primary operators should satisfy the following OPE

$$T(\tilde{x},\tilde{y})\boldsymbol{O}(x,y) \sim \frac{\Delta \boldsymbol{O}}{(\tilde{x}-x)^2} + \frac{2(\tilde{y}-y)\boldsymbol{\xi}\boldsymbol{O}}{(\tilde{x}-x)^3} - \frac{\partial_x \boldsymbol{O}}{\tilde{x}-x} - \frac{(\tilde{y}-y)\partial_y \boldsymbol{O}}{(\tilde{x}-x)^2},$$

$$M(\tilde{x},\tilde{y})\boldsymbol{O}(x,y) \sim \frac{\boldsymbol{\xi}\boldsymbol{O}}{(\tilde{x}-x)^2} + \frac{\partial_y \boldsymbol{O}}{\tilde{x}-x}.$$

- Primary singlets:

The vacuum $|0\rangle \sim 1, \quad \Delta = \xi$=0

vertex operator $V_\alpha =: e^{\alpha\phi}:, \qquad \Delta = 0, \quad \xi = -\frac{\alpha^2}{2}$

- Primary multiplet (rank 2):

$O_0 = i\partial_x\phi, \quad O_1 = i\partial_y\phi, \qquad \Delta = 1, \quad \xi = 0.$

Quasi-pramary multiplets

$$T(x',y')\mathbf{O}(x,y) \sim \cdots + \frac{\Delta \mathbf{O}}{(x'-x)^2} - \frac{2(y'-y)\xi\mathbf{O}}{(x'-x)^3} + \frac{\partial_x \mathbf{O}}{x'-x} - \frac{(y'-y)\partial_y \mathbf{O}}{(x'-x)^2},$$

$$M(x',y')\mathbf{O}(x,y) \sim \cdots + \frac{\xi \mathbf{O}}{(x'-x)^2} + \frac{\partial_y \mathbf{O}}{x'-x}.$$

From general analysis one may expect that T and M form a

rank 2 multiplet with Δ=2, ξ=0.

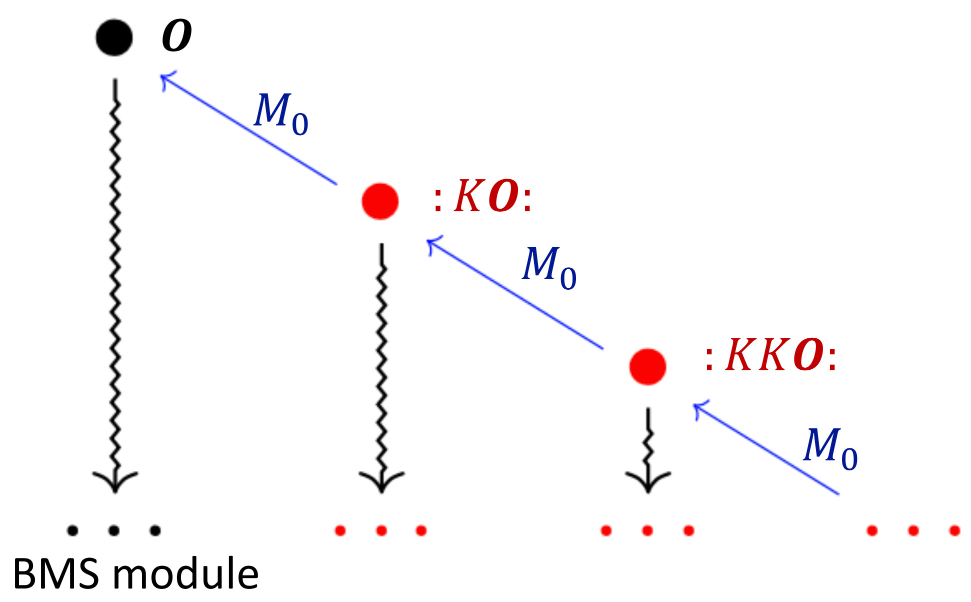
In the free scalar model, however, there is an extra level 2 quasi-primary

$$K \equiv -\frac{1}{2} : \partial_x \phi \partial_x \phi :$$

so that $\mathbf{T} = \{2M, T, K\}$ is a rank 3 multiplet, with $\Delta = 2, \quad \xi = 0.$

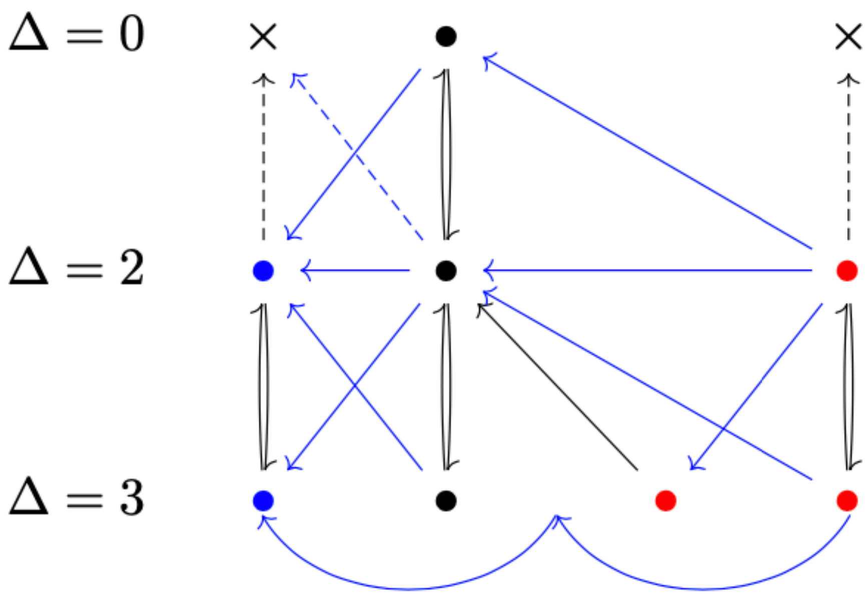
The staggered module

Due to the existence of the extra quasi-primary operator at level 2, states are now organized by an enlarged BMS module, named staggerred module.



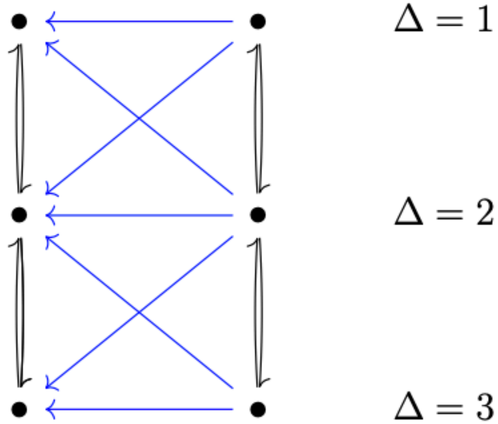
Similar structure also appears in logarithmic CFTs [Gaberdiel-Kausch, Rohsiepe, 96']

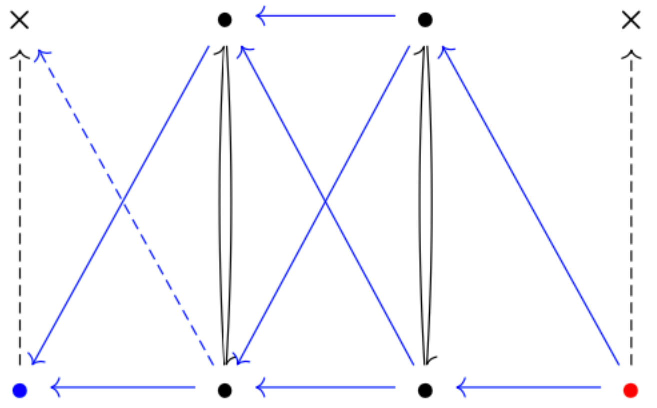
The vacuum module



states with $\Delta = 2$ form a quasi-primary multiplet, from left to right: $|M\rangle$, $|T\rangle$, $|K\rangle$;
states with $\Delta = 3$ from left to right: $L_{-1}|M\rangle$, $L_{-1}|T\rangle$, $M_{-1}|K\rangle$, $L_{-1}|K\rangle$.
The four states at level 3 split into two multiplets: a singlet $L_{-1}|T\rangle - 3M_{-1}|K\rangle$, and a triplet consisting of $L_{-1}|M\rangle$, $L_{-1}|T\rangle + M_{-1}|K\rangle$ and $L_{-1}|K\rangle$.

The O module





states with $\Delta = 1$: $|O_0\rangle$, $|O_1\rangle$;
states with $\Delta = 2$: $L_{-1}|O_0\rangle$, $L_{-1}|O_1\rangle$;
states with $\Delta = 3$: $L_{-1}^2|O_0\rangle$, $L_{-1}^2|O_1\rangle$.

states with $\Delta = 1$: $|O_0\rangle$, $|O_1\rangle$;
states with $\Delta = 3$:
$M_{-2}|O_0\rangle$, $L_{-2}|O_0\rangle$, $L_{-2}|O_1\rangle$, $|KO_1\rangle$.

Correlation functions

Singlets: $\langle\prod_{k=1}^{n} V_{\alpha_k}(x_k, y_k)\rangle = \exp\{\sum_{i<j}^{n}(-\alpha_i\alpha_j)\frac{y_i-y_j}{x_i-x_j}\},\qquad \sum_k \alpha_k = 0$

Multiplets:

$$
\begin{aligned}
\langle O_1 O_1\rangle &= -\frac{1}{x^{2\Delta}}\frac{2y}{x} \\
\langle O_0 O_1\rangle &= \frac{1}{x^{2\Delta}} \\
\langle O_0 O_0\rangle &= 0
\end{aligned}
$$

Consistent with general discussions.

Chen-Hao-Liu-Yu, 20'

More general correlation functions involving multiplets can be determined by requiring that the vacuum is invariant under the global symmetries generated by $L_0, L_1, L_{-1}, M_0, M_1, M_{-1}$

$$q = k_1 + k_2 + 1 - r,$$

2pf: $$\langle O_{k_1}(x_1,y_1) O_{k_2}(x_2,y_2)\rangle = \begin{cases} 0 & \text{for } q<0 \\ d_r\,|x_{12}|^{-2\Delta_1} e^{2\xi_1 \frac{y_{12}}{x_{12}}} \frac{1}{q!}\left(\frac{2y_{12}}{x_{12}}\right)^q, & \text{otherwise} \end{cases}$$

$k_i = 0, \cdots r-1$

3pf: $$\langle \mathcal{O}_i \mathcal{O}_j \mathcal{O}_k \rangle = A_{ijk} B_{ijk} C_{ijk}$$

$$A_{ijk} = \exp\left(\xi_{123}\frac{y_{12}}{x_{12}} + \xi_{312}\frac{y_{31}}{x_{31}} + \xi_{231}\frac{y_{23}}{x_{23}}\right),$$

$$B_{ijk} = |x_{12}|^{-\Delta_{123}} |x_{23}|^{-\Delta_{231}} |x_{31}|^{-\Delta_{312}},$$

$$C_{ijk} = \sum_{a=0}^{r_1-1}\sum_{b=0}^{r_2-1}\sum_{c=0}^{r_3-1} c_{ijk}^{(abc)} \frac{(q_i)^a (q_j)^b (q_k)^c}{a!b!c!},$$

$$\xi_{ijk} \equiv \xi_i + \xi_j - \xi_k$$

$$q_i = \partial_{\xi_i} \ln A_{ijk}$$

The **Hilbert space** is spanned by $|\vec{i},\vec{j};\alpha\rangle = A^{i_1}_{-1}A^{i_2}_{-2}\cdots B^{j_1}_{-1}B^{j_2}_{-2}\cdots|\alpha\rangle$

The **Torus partion function** on the torus defined by

$$spatial\,circle: \quad (\tau,\sigma)\sim(\tau,\sigma+2\pi)$$

$$thermal\,circle: \quad (\tau,\sigma)\sim(\tau-2\pi ib,\sigma-2\pi ia)$$

is given by

$$Z(a,b)\equiv Tr\,e^{-2\pi a(L_0-\frac{c_L}{24})-2\pi b(M_0-\frac{c_M}{24})} = \sqrt{\frac{2}{|b|}}\frac{1}{\eta^2(ia)}$$

which is manifestly modular invariant $Z(a,b)=Z(\frac{1}{a},-\frac{b}{a^2})$

More to be understood

- Further understanding of primary multiplets and staggered module

- The model has central charges $c_L = 2,\ c_M = 0$, whereas the dual of Einstein gravity has $c_L = 0$. model of BMSFT with $c_L = 0$?

- Supersymmetric version

- Interpretation of the primary multiplets and staggered module in the holographic dual

- Implications on tensionless strings

Summary and discsussion

- Finding holographic duality for non-AdS spacetime is very challenging
- Some progress can be made in the bottom-up approach based on asymptotic symmetries
- Geometric picture of holographic entanglement entropy becomes a swing surface in the examples of $flat_3$ /BMSFT and (W)AdS/WCFT dualities.
- A free scalar model of BMSFT can be studied explicitly. Novel features including highest weight multiplets and staggered module appear appear in the model.
- Further study is needed to understand the putative duality, or to kill it.

Thank you!