Gong Show

The preview session by the poster presenters today

#1

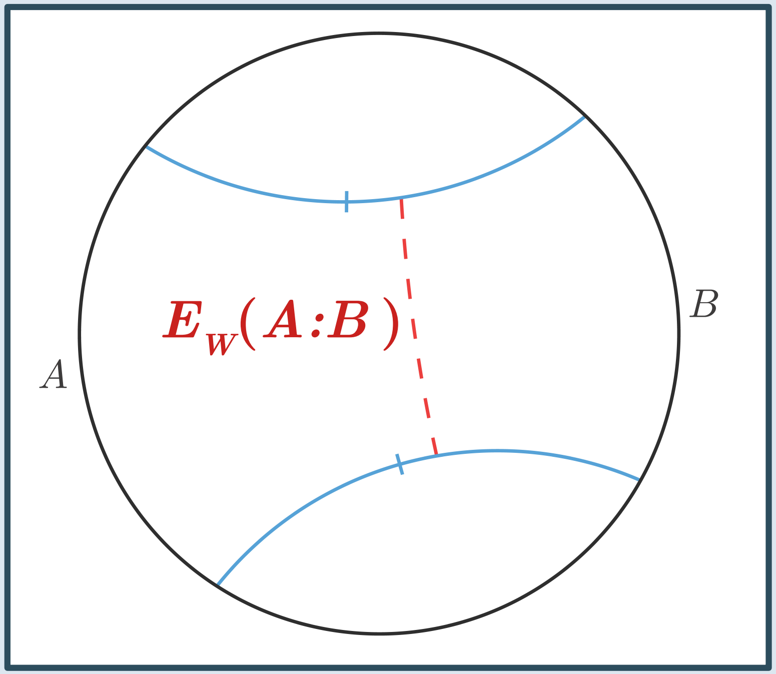
Holographic Entanglement of Purification in Three Acts

Aidan Chatwin-Davies

with Ning Bao, Jason Pollack, and Grant Remmen

#1

$$E_P(\rho_{AB}) = \min_{|\psi\rangle_{AA'BB'}} S(AA')$$



- I -

Multipartite Inequalities

- II -

Wormholes

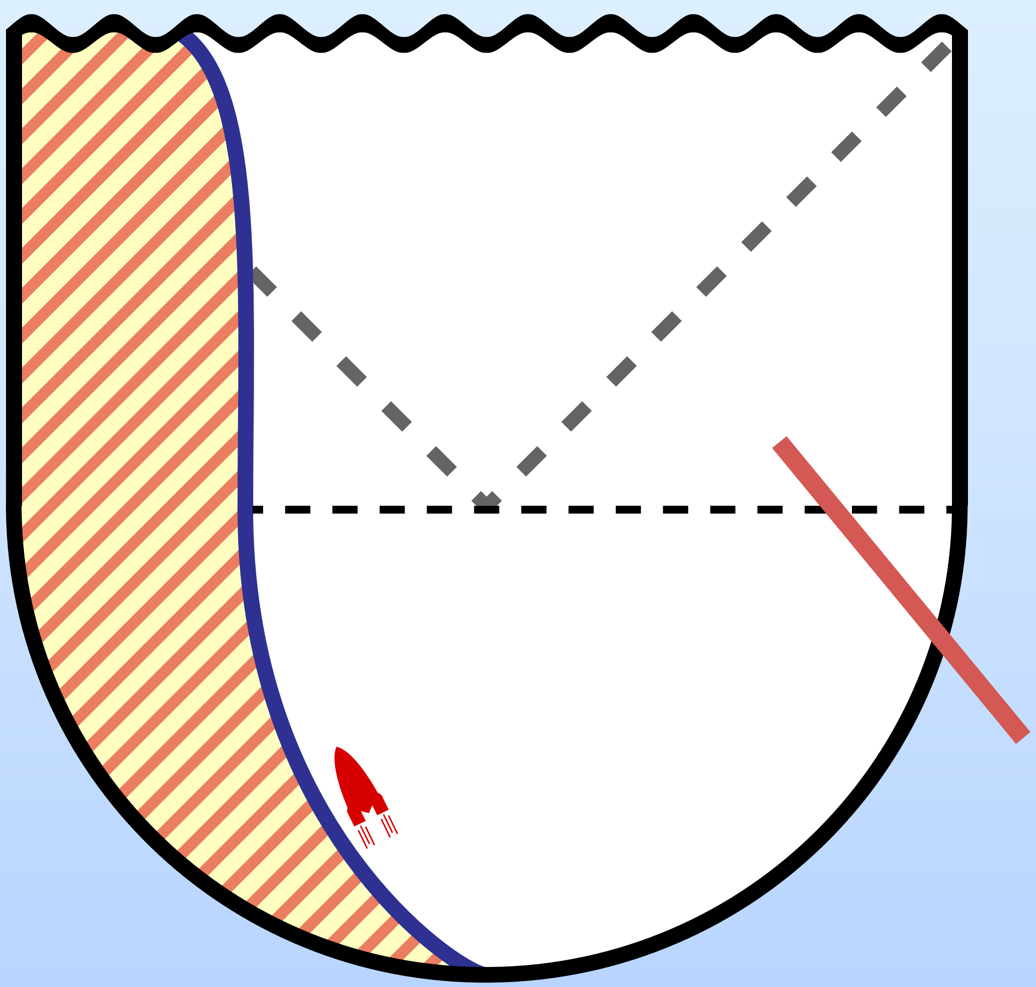
- III -

A Proof With Bit Threads

#2

Black Hole Microstate Cosmology

Sean Cooper, UBC



Holographic Complexity

Entanglement Entropy

d=3 BTZ Geometry

Based on 1810.10601

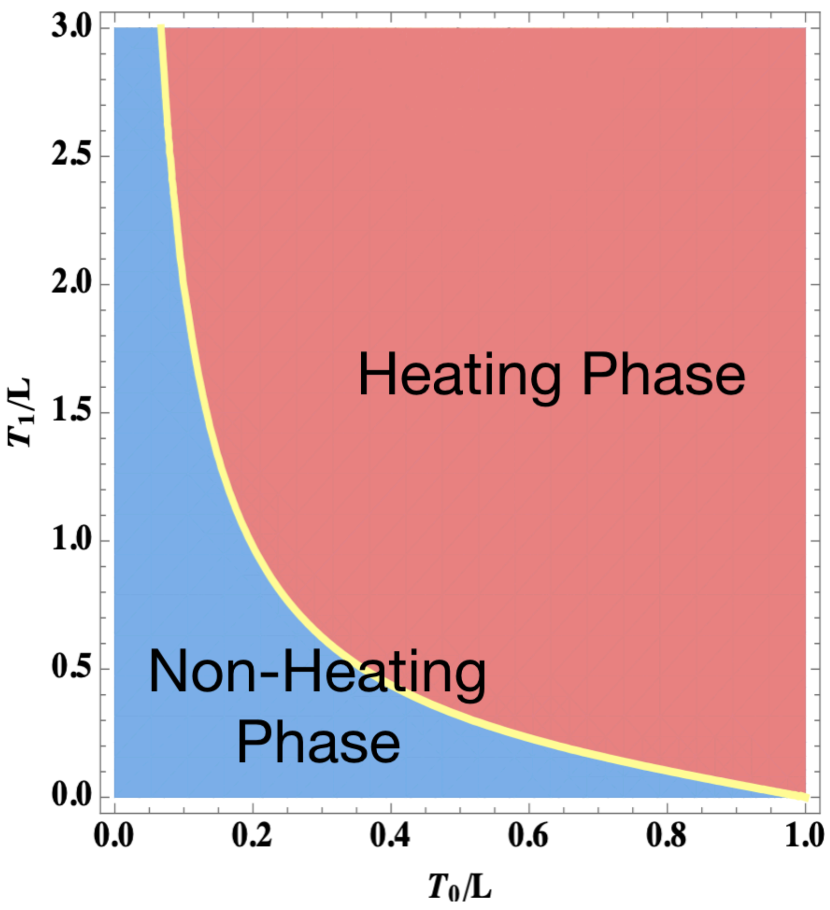
(SC, Rozali, Swingle, Van Raamsdonk, Waddell, Wakeham)

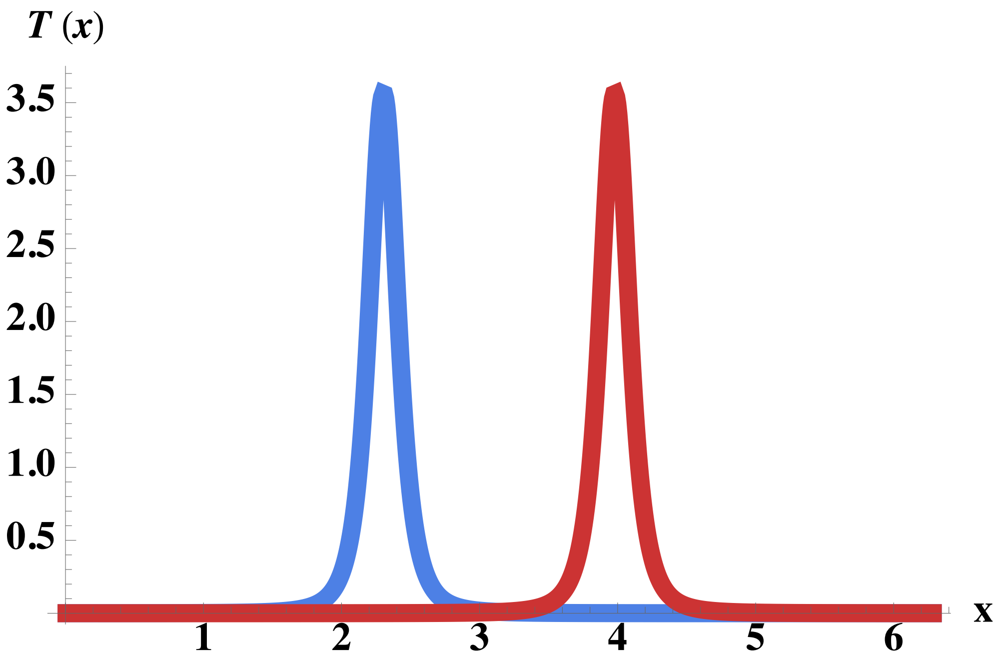
#3

“Swing” in Conformal Field Theory

Ruihua Fan, Yingfei Gu, Ashvin Vishwanath and Xueda Wen

$$E_{\text{total}} \propto c \exp\left(\frac{6}{c} S\right)$$





Wen; Wu, arxiv:1805.00031

arxiv: to appear

#4

Complexity change under **infinitesimal** $(\sim \sigma)$ **local** conformal transformation in AdS_3/CFT_2:

Volume-proposal (CV): $\mathcal{V} \to \mathcal{V}\big|_{\sigma=0} + \sigma \cancel{\mathcal{V}_{(1)}} + \sigma^2 \, \mathcal{V}_{(2)} + \mathcal{O}(\sigma^3)$ (Good)

Action-proposal (CA): $\mathcal{A} \to \mathcal{A}\big|_{\sigma=0} + \sigma \log(\sigma) \mathcal{A}_* + \sigma \mathcal{A}_{(1)} + \mathcal{O}(\sigma^2)$ (Bad)

↑

This term can not be reproduced by Nielsen proposal!

See: Flory, Miekley: 1806.08376 (CV)

Flory: 1902.06499 (CA)

JAGIELLONIAN UNIVERSITY IN KRAKOW

Poster **#4**

Maskawa Hall

funded by NARODOWE CENTRUM NAUKI
grant 2017/24/C/ST2/00469

#5

Non-geometric states in a holographic theory

Wu-zhong Guo, Feng-Li Lin and Jiaju Zhang

arXiv:1806.07595

Our criterion for the geometric states:

The Rényi entropy is $O(c)$ or $O(1/G)$ at the leading order.

Our results (in AdS_3/CFT_2):

1. A series of conditions by local operators
2. The quantum KdV charge/equation $\rightarrow$ classical ones
3. Non-geometric states: superposition of geometric states, some descendant states...

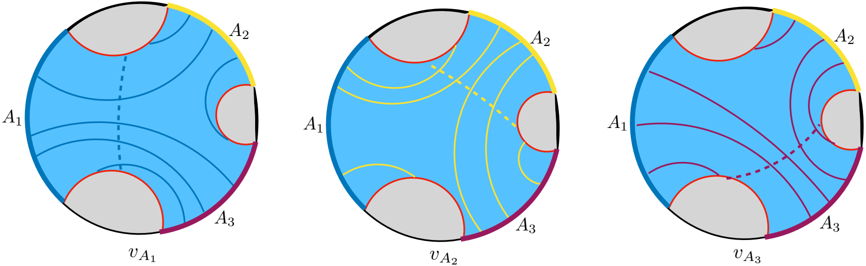
Poster position: **No.5 on June 19 (Maskawa Hall)**

#6

#7

Bit threads and holographic entanglement of purification

- With M. Headrick arXiv: 1906.05970
- Derive bit thread formulation for holographic entanglement of purification
  - Bipartite
  - Multipartite
    - Exist simple max flows with decomposition

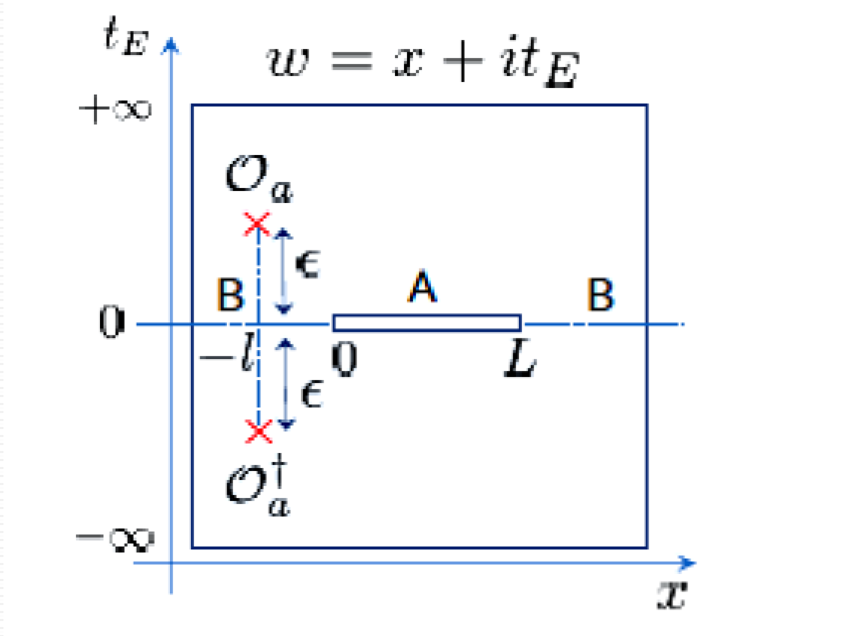


- Maskawa Hall 7

#8

Memory effect of Entanglement entropy in 2D CFT

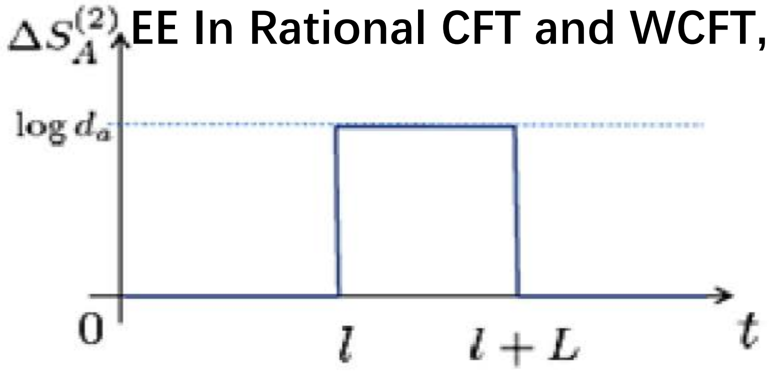
Song He @Jilin U, MPG(AEI)

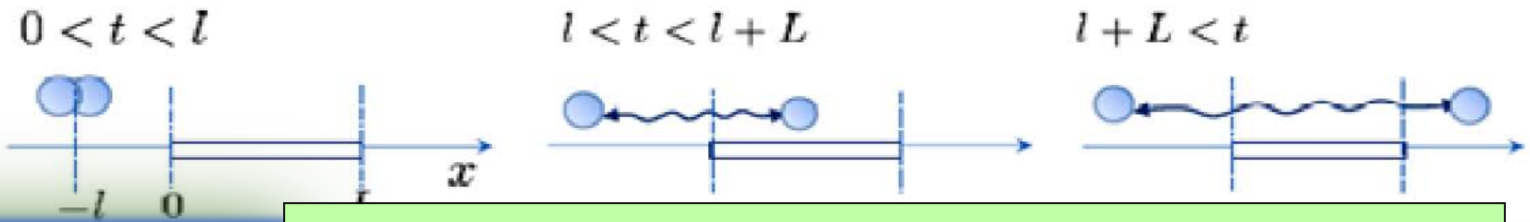


$$\Delta S_A^{(n)}[V_\alpha|0\rangle, V_{\alpha_r}|0\rangle](t) = S_A^{(n)}[V_\alpha(t)]|0\rangle(t) - S_A^{(n)}[V_{\alpha_r}(t)|0\rangle](t)$$

EE In Rational CFT and WCFT, w/ Boundary

Primary operator $\mathcal{O}_a$ ↕ Pseudo-particle





How about 2D Quantum Gravity?

$$\Delta S_{EE}^{(2)} = \Delta S_{EE}^{(2)}[V_\alpha|0\rangle](t\to\infty) - \Delta S_{EE}^{(2)}[V_{\alpha_r}|0\rangle](t\to 0)$$

$$= -\log\left(\frac{F^{SL}_{Q/2,Q/2}\begin{bmatrix}\bar\alpha & \alpha\\ \alpha & \bar\alpha\end{bmatrix}}{F^{SL}_{Q/2,Q/2}\begin{bmatrix}\bar\alpha_r & \alpha_r\\ \alpha_r & \bar\alpha_r\end{bmatrix}}\right)\Bigg|_{p\to 0},$$

$$\alpha, \alpha_r \in \{Q/2 + ip\}, p \in \mathbb{R}.$$

The Liouville field theory action

$$S_L = \frac{1}{4\pi}\int d^2\xi\sqrt{g}\left[\partial_a\phi\partial_b\phi g^{ab} + QR\phi + 4\pi\mu e^{2b\phi}\right]$$

#9

Shrinking of Operators in Quantum Error Correction and AdS/CFT

arXiv :1906.××××× Hayato Hirai (Osaka Univ.)

- For a given bipartite pure state $|\psi\rangle_{AB} \in \mathcal{H}_A \otimes \mathcal{H}_B$,

$$\mathcal{O}_{AB} \in \mathcal{S}_{\mathcal{L}}(A\,;|\psi\rangle_{AB})$$

$$\Leftrightarrow \quad {}^{\exists}\mathcal{O}_A \quad s.t. \quad \mathcal{O}_{AB}|\psi\rangle_{AB} = \mathcal{O}_A \otimes I_B|\psi\rangle_{AB}$$

$\sim$ Finite dimensional version of Reeh-Schlieder theorem

- A formula for constructing the decoder of QEC against erasure errors.

- In ***"subsystem code with complementarity recovery"*** (Harlow '16)

Bulk		Boundary
$\mathcal{H}_{\mathcal{E}_A} \otimes \mathcal{H}_{\mathcal{E}_{\overline{A}}}$		$\mathcal{H}_{code} \subset \mathcal{H}_A \otimes \mathcal{H}_{\overline{A}}$
$\phi_{bulk} \in \mathcal{S}_{bulk}(\mathcal{E}_A; \widetilde{\mathcal{H}}_{bulk})$	dual $\longleftrightarrow$	$\phi_{bdry} \in \mathcal{S}_{bdry}(A; \mathcal{H}_{code})$

#10

CAPACITY AND RELATIVE CAPACITY OF ENTANGLEMENT

J. de Boer, V. Godet, J. Järvelä, J. Kastikainen, E. Keski-Vakkuri

Classical information is an expectation value of a random variable,

$$H = E\left[I(X)\right] = E\left[-\log p(X)\right]$$

the variance of which characterizes spread about the average information content,

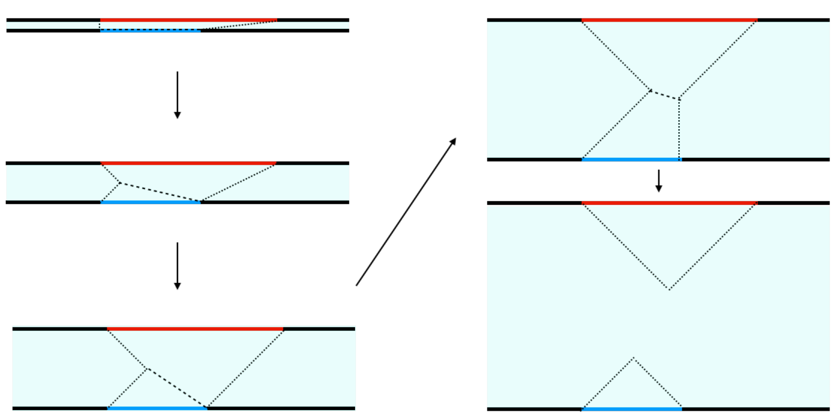
$$\Delta^2 H = E\left[(I(X) - E[I(X)])^2\right] = E\left[(-\log p(X))^2\right] - H^2.$$

The quantum counterpart of this information measure is called the *capacity of entanglement* C_E. We study its properties and related quantities in many different theories.

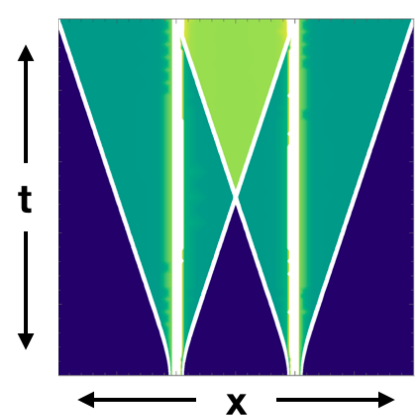
#11

Quantum vs. classical information: holographic negativity and scrambling

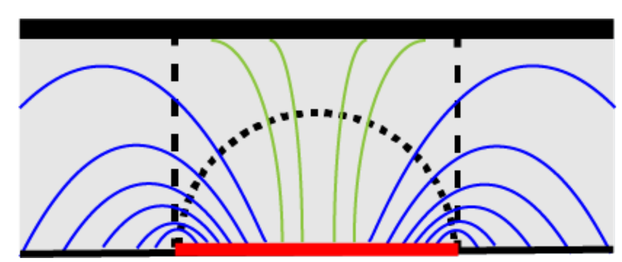
$$\text{Holographic Logarithmic Negativity} \stackrel{?}{=} \text{(Backreacting) } E_W$$



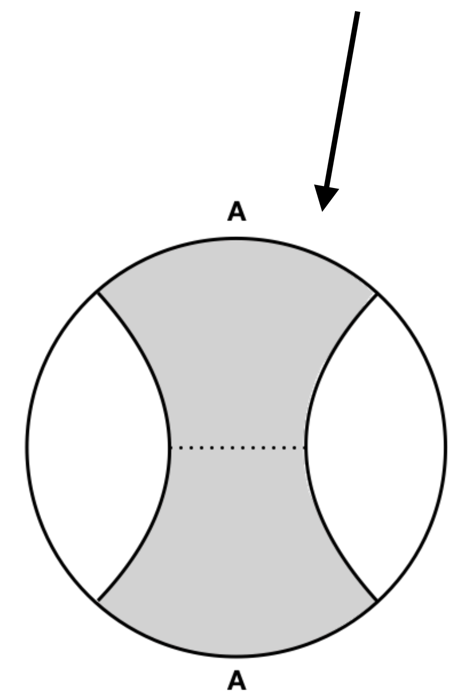
Line tension



Tsunami



Entanglement contour



Entanglement wedge

JKF, Ryu, S. arXiv: [hep-th] **1808.00446** "*Entanglement negativity and minimal entanglement wedge cross sections in holographic theories,*" Phys. Rev. D 99, 106014 (2019)

JKF, MacCormack, I., Ryu, S. arXiv: [hep-th] **1902.04654** "*Holographic entanglement contour, bit threads, and the entanglement tsunami*"

JKF, Nozaki, M., Ryu, S., Tan, M.T. arXiv: [hep-th] **1906.xxxxx** "*Quantum vs. classical information: operator negativity as a probe of scrambling*"

JKF, Shapourian, H., Ryu, S. "*The negativity contour: a quasi-local measure of entanglement for mixed states,*" In Preparation.

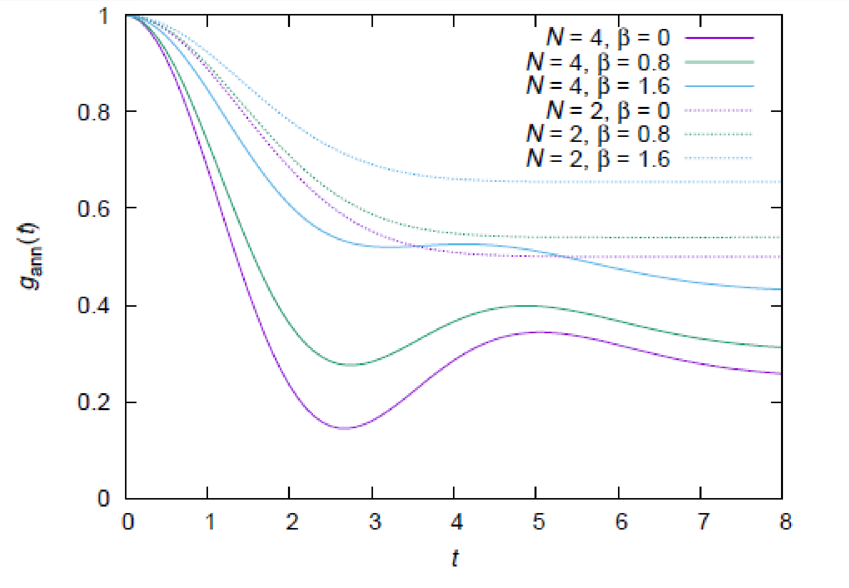
THE UNIVERSITY OF CHICAGO

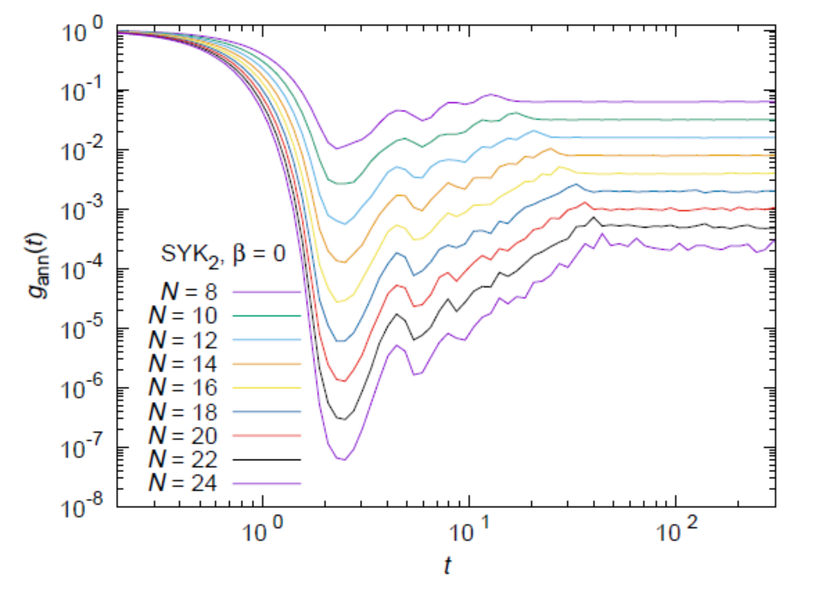
KADANOFF CENTER FOR THEORETICAL PHYSICS

#12

Randomness and chaos in qubit models

Poster # : 12





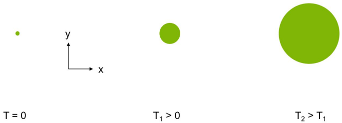
Pak Hang Chris Lau (NCTS), Chen-Te Ma (NTU),
Jeff Murugan (Cape Town U.) and Masaki Tezuka (Kyoto U)

arXiv:1812.04770
(accepted by PLB)

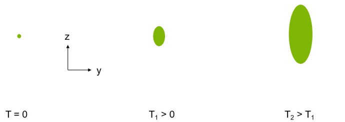
#13

EFT of Dissipative String Fluids

- Write S_{eff} that describes gapless hydrodynamic modes associated with a conserved current. For a one-form symmetry, $\partial_\mu J^{\mu\nu} = 0$.
- Degree of freedom in S_{eff} is dynamical gauge field A_μ.
- **Symmetry-preserving phase:** dissipative fluid of line charges.
  - Introduce finite vector chemical potential μ_i. With higher-form analog of electric field, E_{ij}, we get distinct conductivities for components of E_{ij} along and orthogonal to μ_i, both ≥ 0 due to $\text{Im}[S] \geq 0$ (from unitarity).
  - 4 different parity-invariant actions. In one case, we get a term which gives a "Hall conductivity"– current J^{xz} generated in response to electric field E^{yz}.
- Coupling of different components of vector charge density $\Rightarrow$ rich diffusion.



$\mathbf{J}(t=0,\mathbf{x}) = \mathcal{J}_0\delta(x)\delta(y)\hat{\mathbf{z}} \quad \mathbf{J}(t,\mathbf{x}) = \frac{\mathcal{J}_0}{4\pi t C_3} e^{-\frac{x^2+y^2}{4C_3 t}}\hat{\mathbf{z}} \quad C_3 = \frac{\sigma_\parallel}{\chi_\parallel}$



$\mathbf{J}(t=0,\mathbf{x}) = \mathcal{J}_0\delta(y)\delta(z)\hat{\mathbf{x}} \quad \mathbf{J}(t,\mathbf{x}) = \frac{\mathcal{J}_0}{4\pi t\sqrt{C_1 C_2}} e^{-\frac{y^2}{4C_1 t}-\frac{z^2}{4C_2 t}}\hat{\mathbf{x}} \quad C_1 = \frac{\sigma_\perp}{\chi_\perp} \quad C_2 = \frac{\sigma_\parallel}{\chi_\perp}$

#14

Universal Structure of Covariant Holographic Two-Point Functions In Massless Higher-Order Gravities

Yue-Zhou Li, Tianjin University

1. Massless gravity: the linear perturbation around AdS vacuum only contains the massless graviton.

- Example: Gauss-Bonnet gravity, Lovelock gravity, Quasi-topological gravity
- We study holographic two-point functions of stress-tensors in massless gravities

2. Universal structures and relations were found and conjectured for massless gravities.

- Tensor structure follows the form that CFT requires

$$\langle T_{ij}(x) T_{kl}(0) \rangle \sim \frac{\mathcal{I}_{ijkl}(x)}{x^{2d}} \,,$$

- The central charge relations between $\mathcal{C}_T$ (c in $d=4$) and a

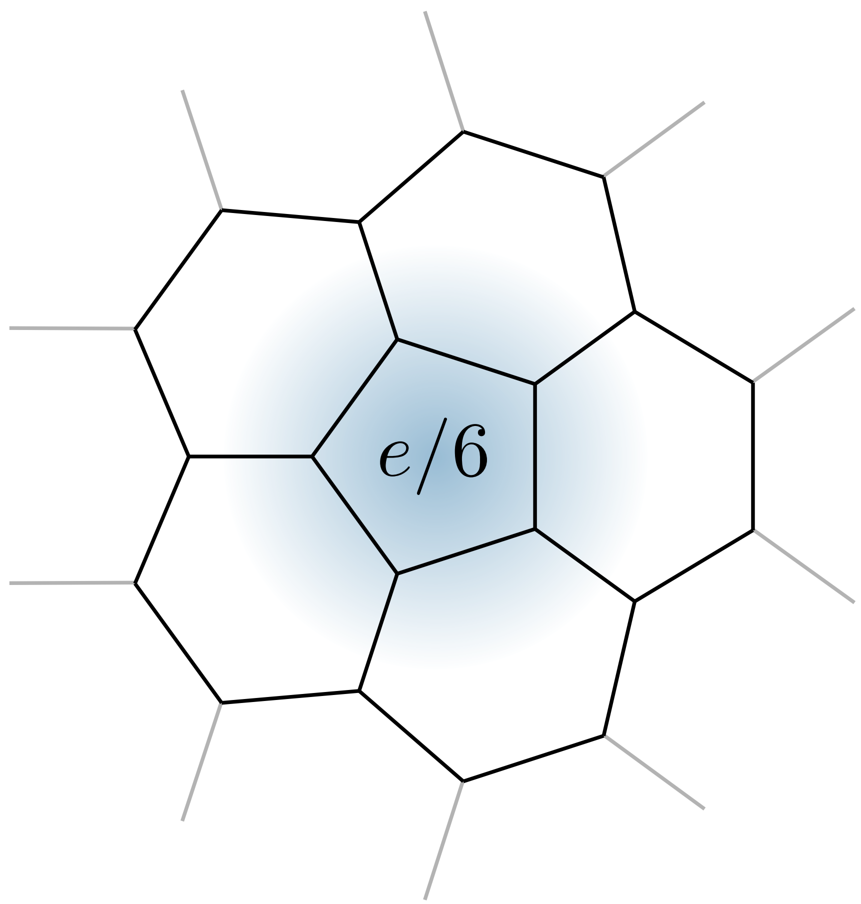
$$\mathcal{C}_T = \frac{1}{d-1}\, \ell \frac{\partial a}{\partial \ell} \,, \qquad \mathcal{C}_T|_{d=4} = c$$

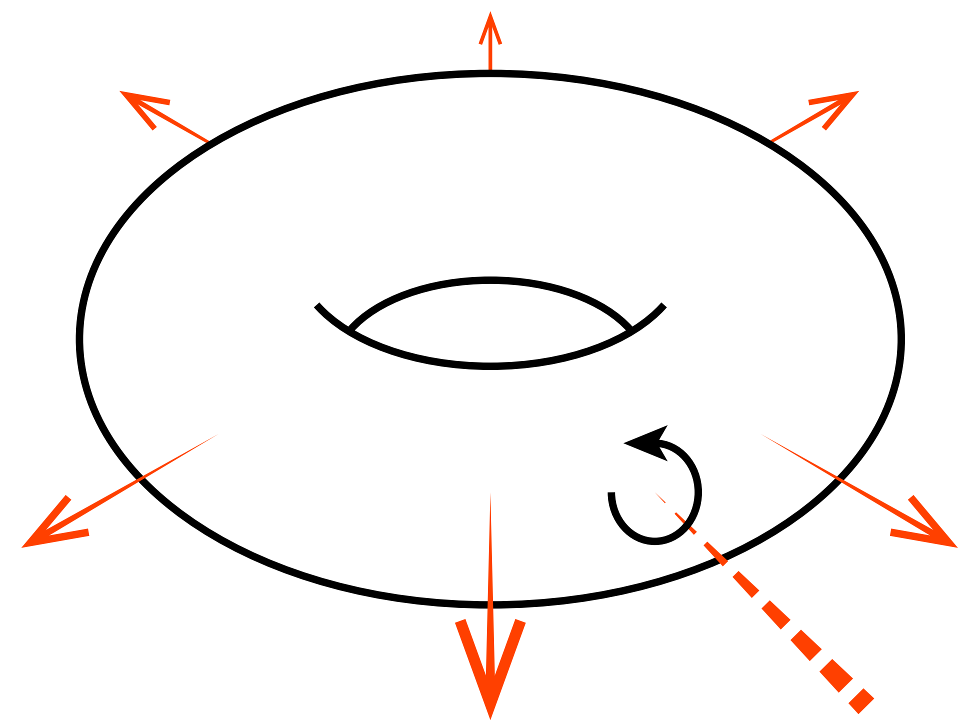
#15

Shift Insulators: Rotation Protected 2D Topological Crystalline Insulators

Shang Liu, Ashvin Vishwanath, Eslam Khalaf

1809.01636, to appear on PRX.





$$\mathscr{L}_{\mathrm{eff}} = -\frac{S}{2\pi} A \wedge \mathrm{d}\omega \,.$$

Wen, Zee, 1992.

Jun-19, Maskawa Hall

#16

Holographic complexity equals which action?

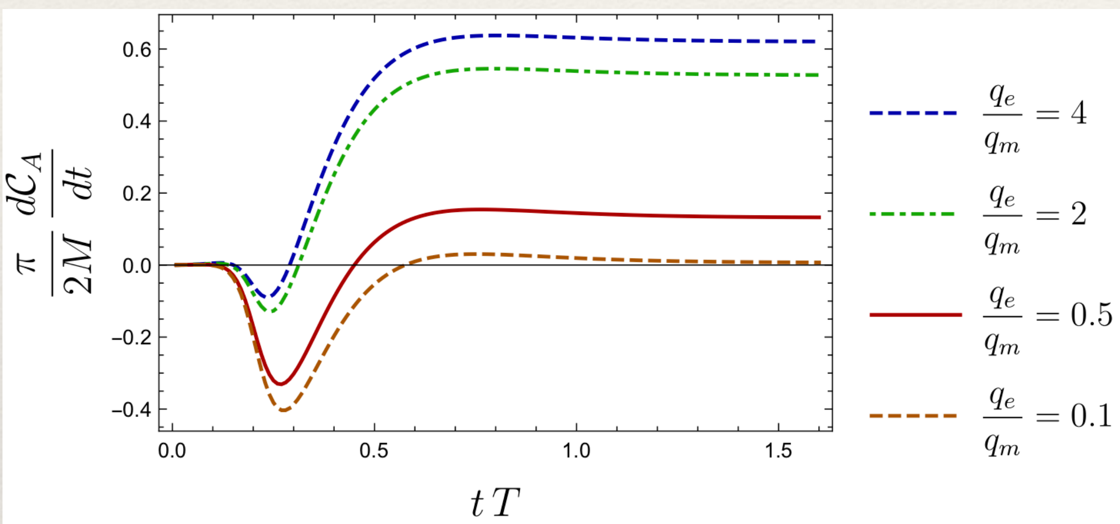
arXiv:1901.00014
JHEP 160 1902 (2019)

Complexity = Action $\mathcal{C}_A = \frac{I_{WDW}}{\pi\hbar}$

Dyonic solution

$$F = \frac{g}{\sqrt{4\pi G_N}}\left(\frac{q_e}{r^2}\,dr\wedge dt + q_m \sin\theta\, d\phi\wedge d\theta\right)$$

$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega_2^2 \qquad f(r) = 1 + \frac{r^2}{L^2} - \frac{\omega}{r} + \frac{q_e^2+q_m^2}{r^2}$$



Same classical geometry, different complexity growth given by ratio of charges!

Solution: Importance of surface terms to the action! $I_{\mu Q} = \frac{\gamma}{g^2}\int_{\partial\mathcal{M}} d\Sigma_\mu F^{\mu\nu}A_\nu$

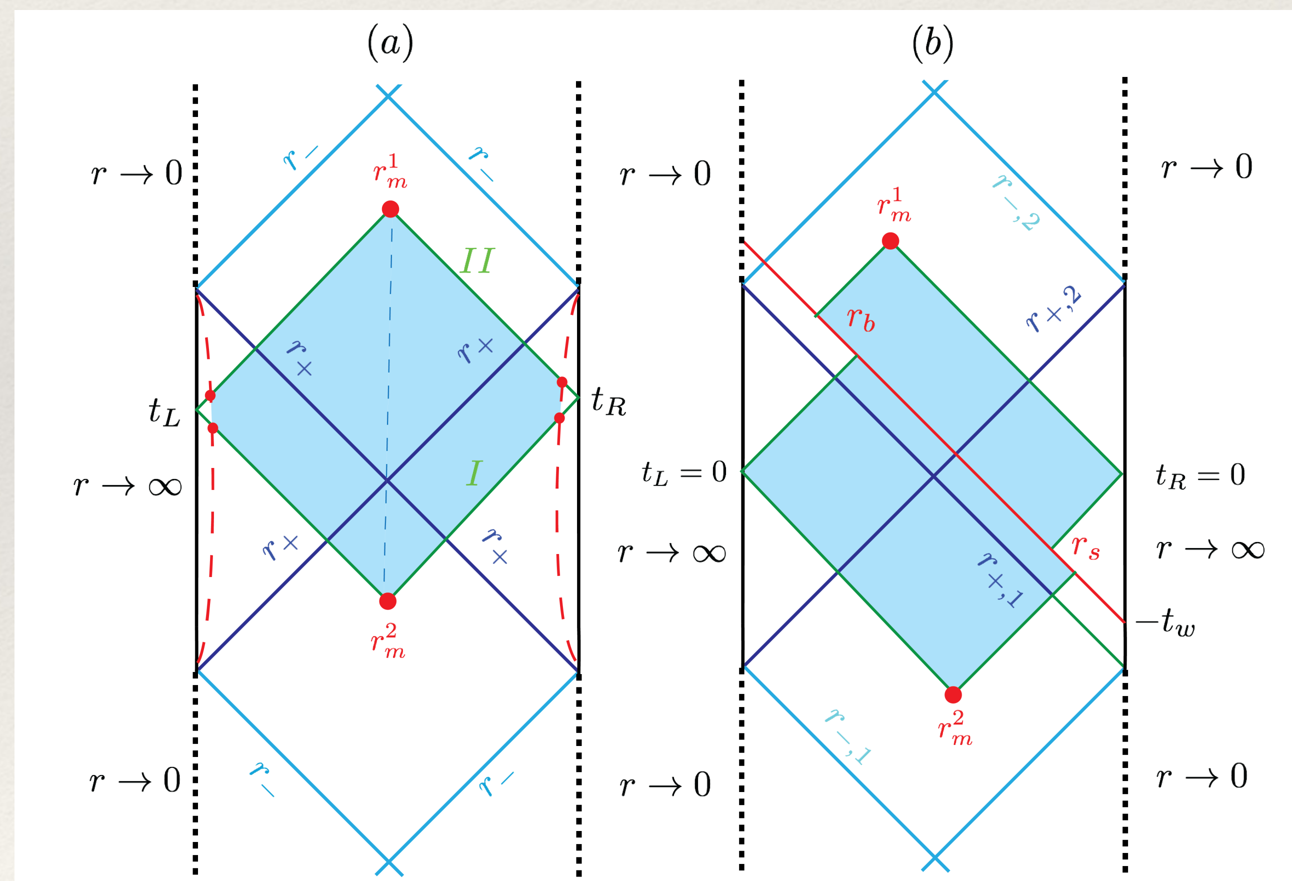
Interesting consequences for the CA proposal in Jackiw-Teitelboim theory of gravity!

Gravity + Maxwell Field

$$I_{\rm tot} = I_{\rm EH} + I_{\rm Max} + I_{\rm surf} + I_{\rm ct}$$

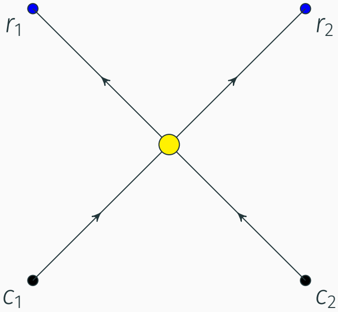
$$I_{\rm EH} = \frac{1}{16\pi G_N}\int_{\mathcal{M}} d^4x\sqrt{-g}\left(\mathcal{R} + \frac{6}{L^2}\right)$$

$$I_{\rm Max} = -\frac{1}{4g^2}\int_{\mathcal{M}} d^4x\sqrt{-g}F_{\mu\nu}F^{\mu\nu}$$

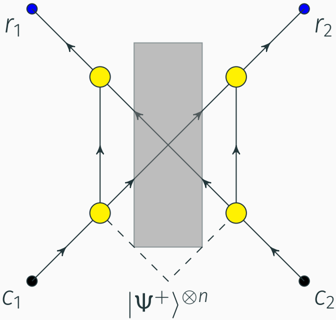


Hugo Marrochio
PERIMETER INSTITUTE
UNIVERSITY OF WATERLOO

#17



(a)



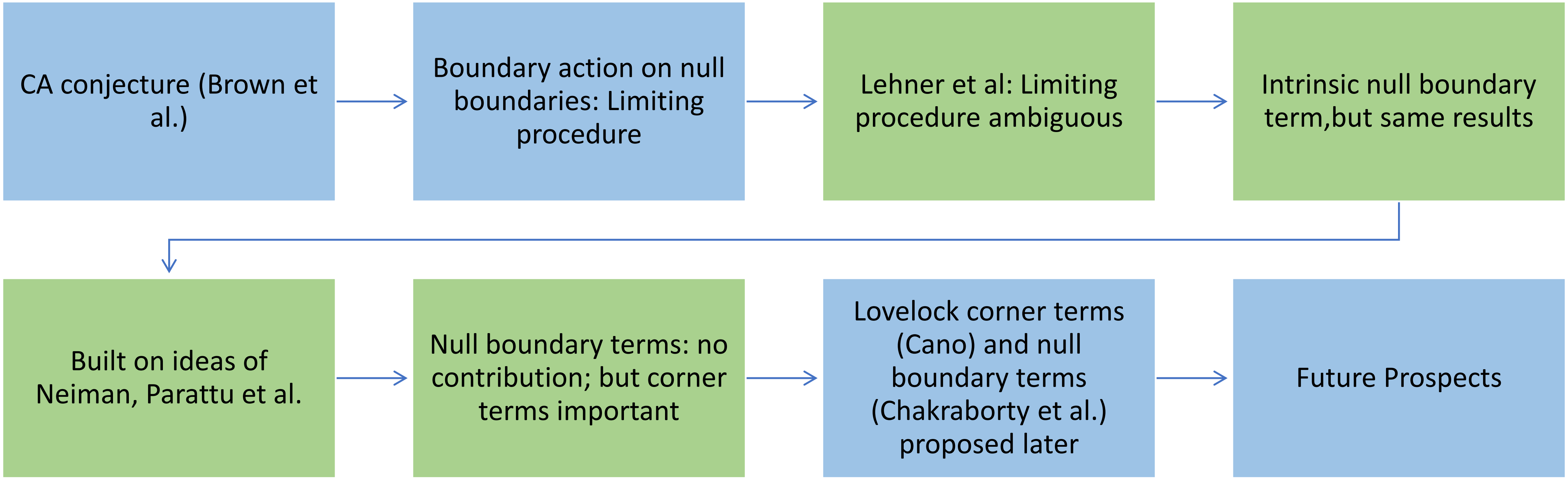
(b)

- In the cryptographic task of **position verification**, it has been understood that entanglement can be used to replace access to geometric regions.

#18

Null Boundary Terms in Gravity

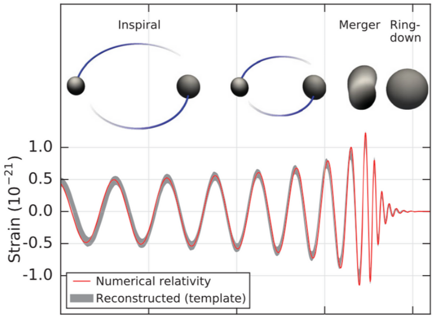
Krishna Mohan Parattu, PUCV, Chile



#19

Conformally Soft Theorem in Gauge Theory

Monica Pate, **Ana Raclariu**, Andrew Strominger



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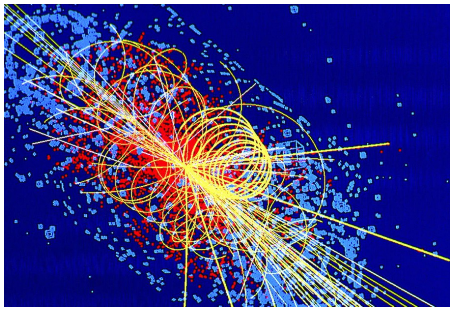

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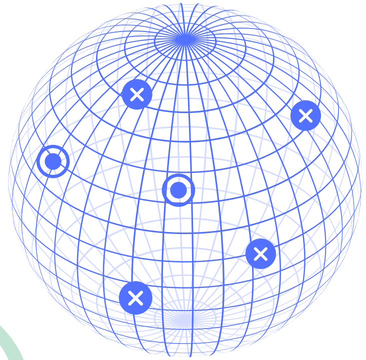
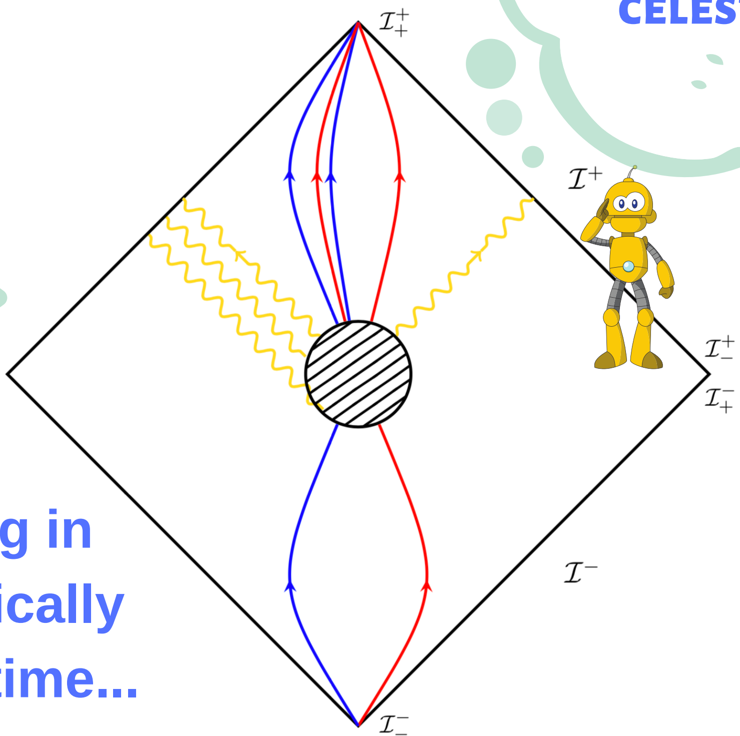
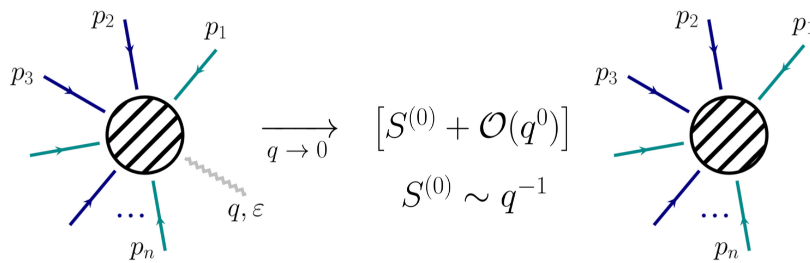
- Lorentz group ~ global conformal group on celestial sphere
- 4D energy → 2D conformal dimension
- Holographic description of scattering in 4D gauge theories?



Is there an analog of the soft theorem for celestial amplitudes?



...is universal in the low energy limit.



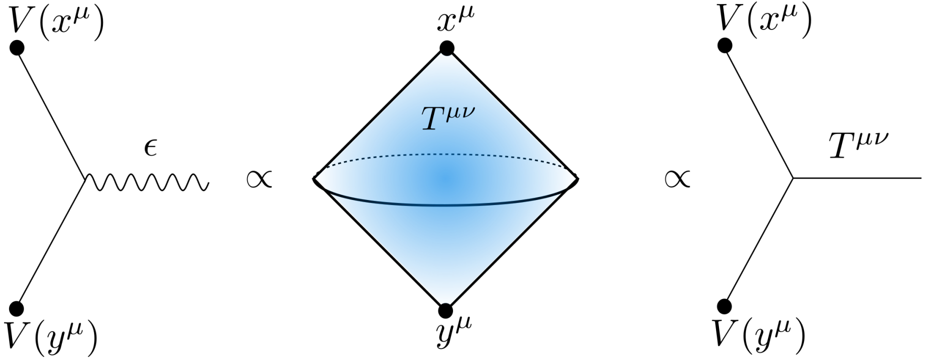
Soft theorem ⟷ Symmetry

Scattering in asymptotically flat spacetime...

#20

Kinematic Space, Reparameterizations, and Conformal Blocks

Wyatt Reeves, University of British Columbia

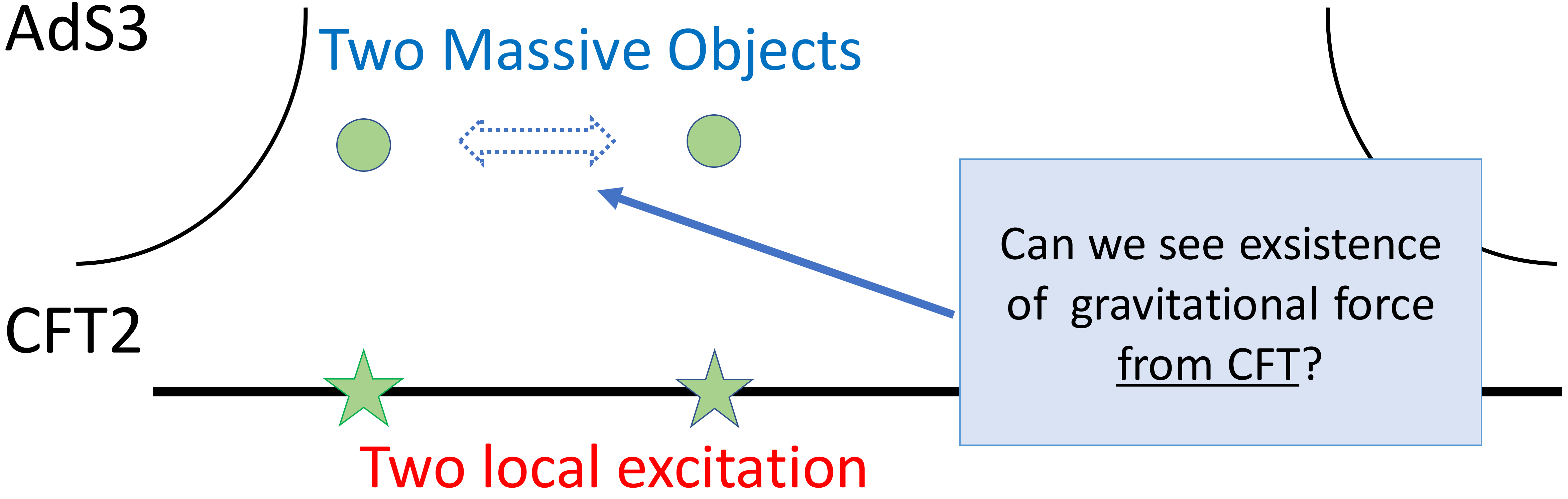


The coupling of reparameterization modes to operators, the kinematic space operator for the stress tensor, and the stress tensor OPE block are equivalent.

#21

Double Local Quenches in 2D CFTs & Gravitational Force [arXiv:1905.08265]

P. Caputa, T. Numasawa, T. Shimaji(YITP), T. Takayanagi, Z. Wei



#22

Holographic Entanglement Entropy in $AdS_4/BCFT_3$ and the Willmore Functional

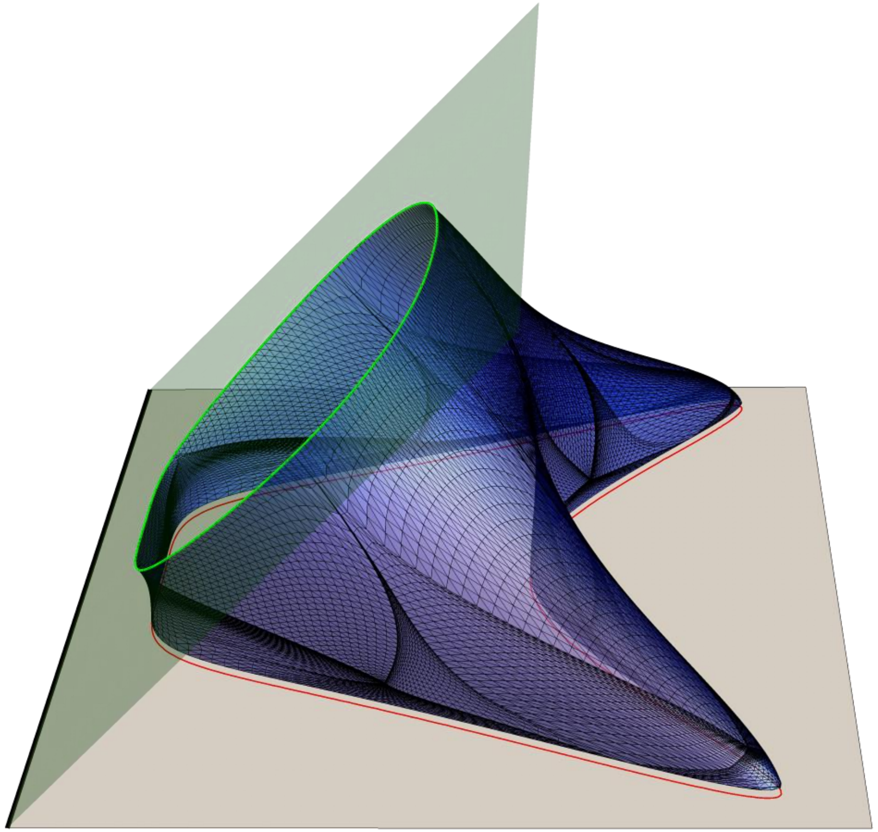
Jacopo Sisti

D. Seminara, J. Sisti and E. Tonni, JHEP **1711** (2017) 076
D. Seminara, J. Sisti and E. Tonni, JHEP **1808** (2018) 164

- $AdS_4/BCFT_3$ ⟹ Boundary in the CFT
- Holographic Entanglement Entropy

$$\mathcal{A}[\hat{\gamma}_\varepsilon] = \frac{P_{A,B}}{\varepsilon} - F_A + o(1)$$

- Shape dependence in the subleading term F_A
  Willmore Functional
- Analytic solutions and dependence on the boundary conditions
- Logarithmic Terms



#23

Holographic Renormalized Entanglement Entropy and its application

- Holographic entanglement entropy has a geometrical interpretation as the area of bulk extending minimal entangling surface.
- Derivation of holographic renormalized entanglement entropy via geometric replica trick.
- Holographic renormalizated action can be used to derive renormalized entanglement entropy.
- The first law of entanglement entropy relates the dynamics of bulk theory with variation of entanglement entropy.
- Holographic renormalization provides a method for reconstruction of spacetime.
- The renormalized version of first law of entanglement entropy.

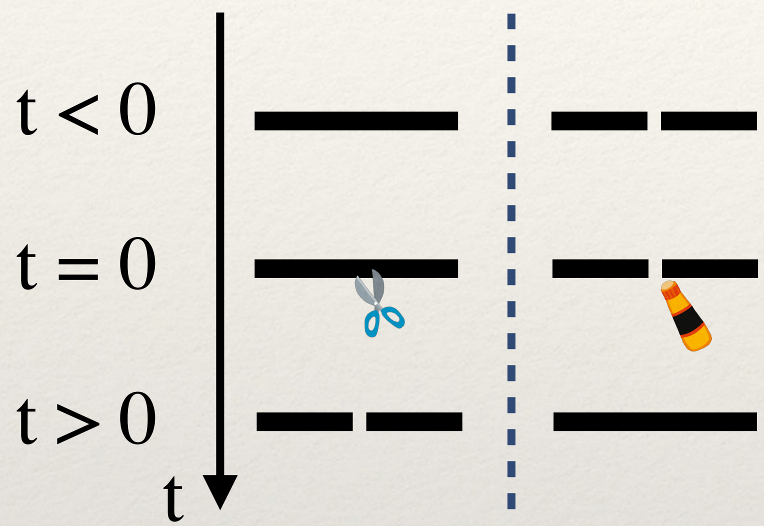
#24

Holographic Quantum Circuits from Splitting/Joining Local Quenches

Zixia Wei (YITP, Kyoto U.)

Based on: JHEP03(2019)165 with T. Shimaji & T. Takayanagi

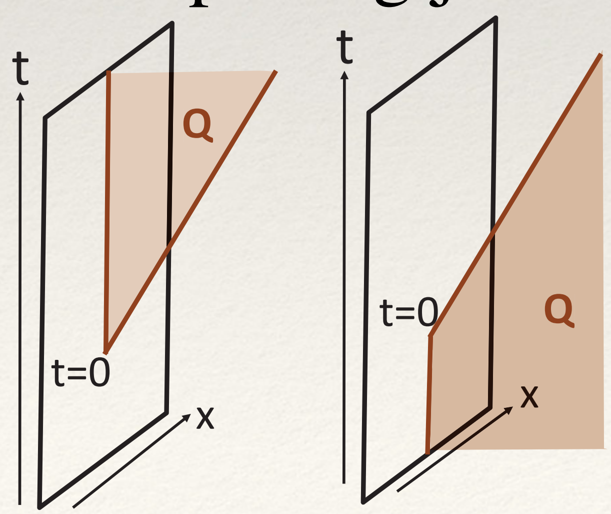
1+1D quantum system (analyzed in CFT)



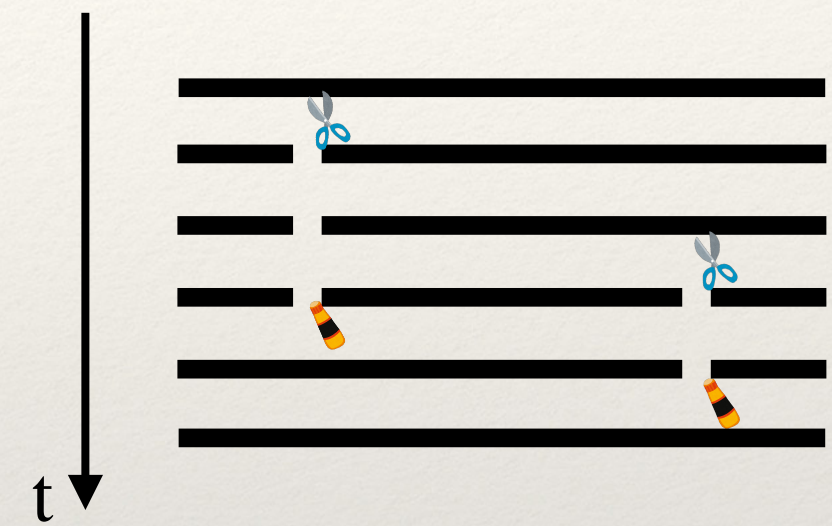
splitting / joining quench

Their gravity duals: splitting/joining spacetime

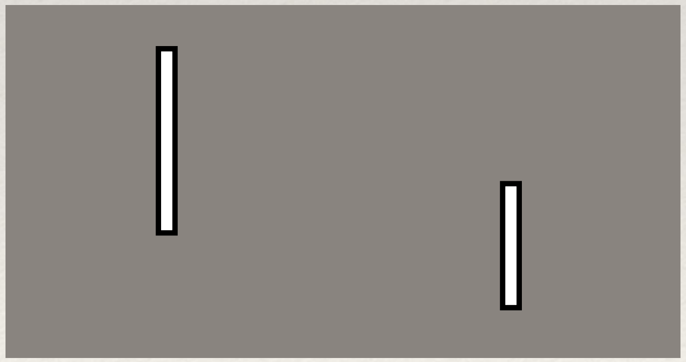
Q: boundary of spacetime



Combining splitting/joining quench



continuously…



Quantum Circuits!

(We can use bulk geometry to figure out properties of such quantum circuits)

#25

Derive three dimensional geometries from entanglement entropies of CFT_2

Entanglement entropy $\Longrightarrow$ Leading behavior of a bulk geometry

Requirements

- We ONLY use the results of CFT_2.
- We can NOT use any result of AdS/CFT.
- We can NOT assume CFT and bulk geometry possess the same SO(2, d) symmetry. Symmetry argument is a necessary but not a sufficient condition.
- We can NOT assume the geometries satisfying the Einstein's equation.

Difficulties

- How to derive the higher dimensional theory from the lower one?
- How to extract the metric from the minimal surfaces (geodesic length)?
- How to include the time-like direction?

Our Results (Peng Wang, HW, Haitang Yang)

- (arXiv: 1710.08448) Infinite size $CFT_2 \Longrightarrow$ asymptotic AdS.
- (arXiv: 1809.01355) CFT_2 at finite temperature $\Longrightarrow$ BTZ black hole.
- (arXiv: 1811.07758) $T\bar{T}$ deformed $CFT_2 \Longrightarrow$ deformed BTZ black hole. Highly excited states $\Longrightarrow$ conical defect in the global AdS.

#26

Spin-dipole entangled quantum liquid

arXiv: 1903.03567

Masahiko G. Yamada and Yasuhiro Tada

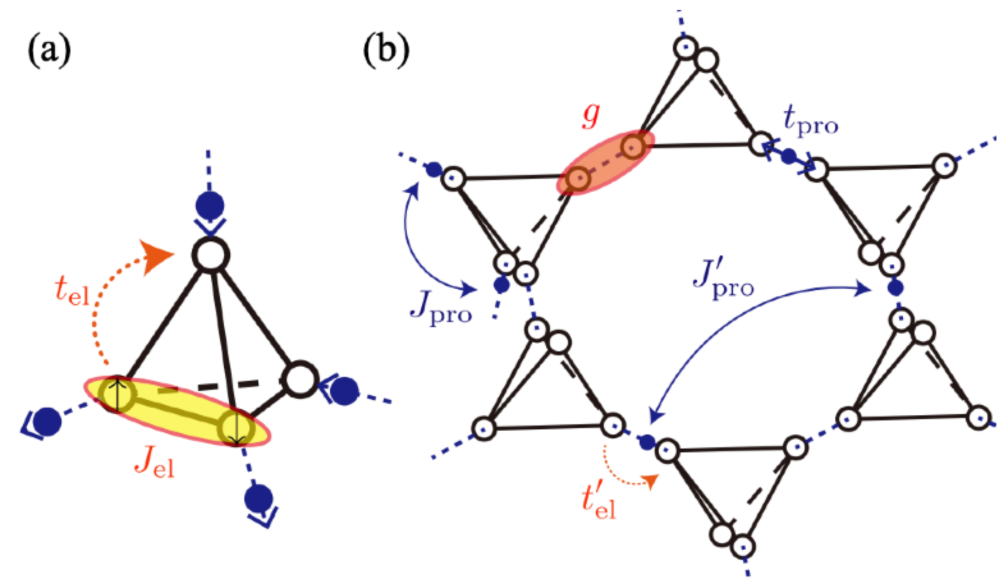
We propose a new hybrid liquid state with a strong entanglement between the proton and electron sectors.

$$H = H_{\mathrm{el}} + H_{\mathrm{pro}} + H_{\mathrm{el-pro}}, \tag{1}$$

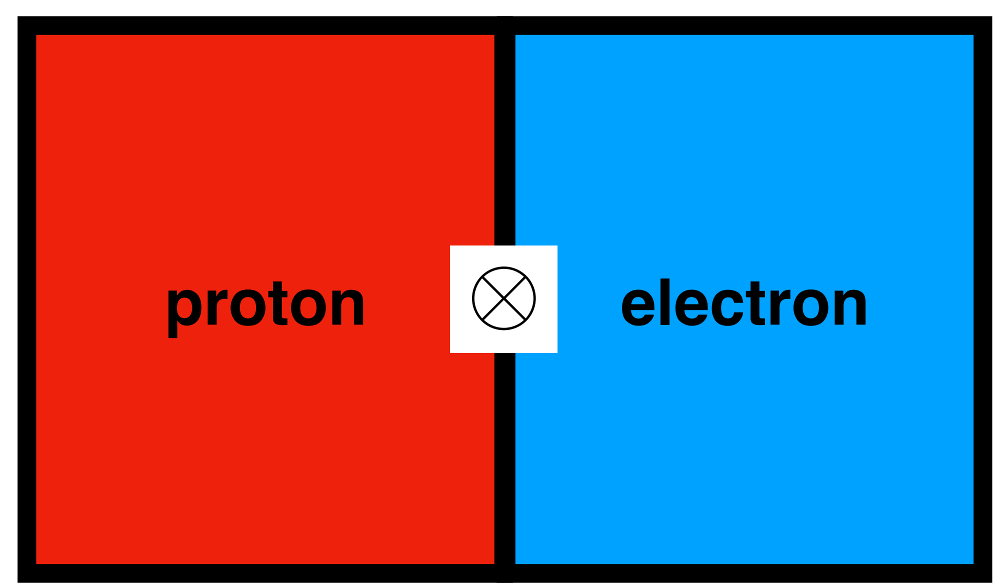
$$H_{\mathrm{el}} = t_{\mathrm{el}} \sum_{\boxtimes} \sum_{i,j\in\boxtimes} c^{\dagger}_{is} c_{js} + J_{\mathrm{el}} \sum_{\boxtimes} \sum_{i,j\in\boxtimes} \boldsymbol{S}_i \cdot \boldsymbol{S}_j, \tag{2}$$

$$H_{\mathrm{pro}} = t_{\mathrm{pro}} \sum_{\langle ij \rangle} \sigma^x_{ij} + J_{\mathrm{pro}} \sum_{\langle\langle ij\rangle,\langle kl\rangle\rangle} \sigma^z_{ij}\sigma^z_{kl}, \tag{3}$$

$$H_{\mathrm{el-pro}} = g \sum_{\langle ij \rangle} (n_j - n_i)\sigma^z_{ij}. \tag{4}$$



Total Hilbert space



- Quantum spin liquid + quantum dipole liquid
- Volume law of entanglement

$$S_{\mathrm{EE}} \sim \log(\#\text{ of flippable ice states}) \sim O(V)$$

#27

Quantum Information Capsule and Information Delocalization

No. 27
@Y306

Koji Yamaguchi,
Tohoku university

[KY, N. Watamura, M. Hotta, Phys. Lett. A 383, 12, 1255 (2019)]
[KY, M.Hotta, arXiv:1902.05675 [quant-ph]]

Question:
Where is information stored in entangled system?

Entanglement delocalizes information

Carrier of delocalized information:

- (Purification) Partners ⟵ Common picture
- Quantum Information Capsule (QIC) ⟵ New!

A new result related with scrambling:

- Emergence of Decoupled QICs in chaotic systems

[KY, M.Hotta, arXiv:1906.xxxxx]

#28

Should complexity be non-unitary invariant and non-bi-invariant?

Many people said YES but we want to say NO!

Run-Qiu Yang, *Quantum Universe Center, Korea Institute for Advanced Study*

Background

Complexity is important for both QFTs and black holes

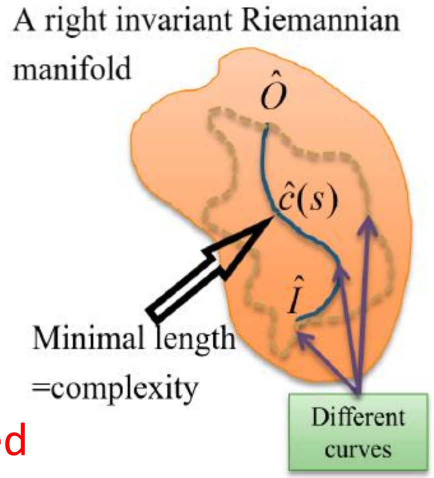
Current study: → followed Nielsen's right-invariant complexity geometry

$\Rightarrow$ Choose a Lie group G;

$\Rightarrow$ Choose a norm $\tilde{F}(H)$ Lie algebra;

$\Rightarrow$ Compute curve length $L[c] = \int_0^1 \tilde{F}(H(s))\mathrm{d}s$;

$\Rightarrow \mathcal{C}(\hat{U}) = \min\{L[c] \mid \overleftarrow{\mathcal{P}} \exp[\int_0^1 iH(s)\mathrm{d}s] = \hat{U}\}$.



Complexity in many literatures is required non-unitary invariant!

Shortages:

- There are two different complexities but no way tell us which one is correct
- Too parameters to be a controlled and predictive theory
- Conflict with current framework of QM/QFT

To be consistent with QM/QFT, complexity in QM/QFT should be unitary invariant!

#29

Quantum Chaos and Schwarzian Theory

Junggi Yoon, KIAS

❖ Schwarzian Theory: $S = \int d\tau \left(-\frac{c}{12}\mathrm{Sch}\left[\phi(\tau),\tau\right] + b_0[\phi'(\tau)]^2\right)$

❖ Bound on chaos from Stability [JY, 1906.08815]

$$b_0 \geqq -\frac{c}{24}$$

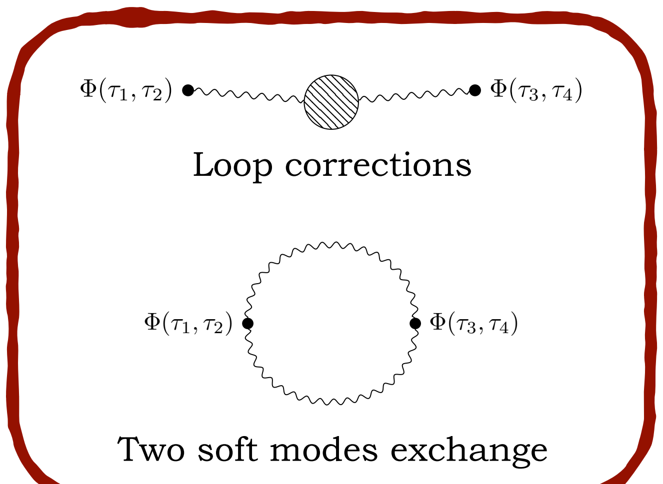
Stability
[E. Witten, 1988]

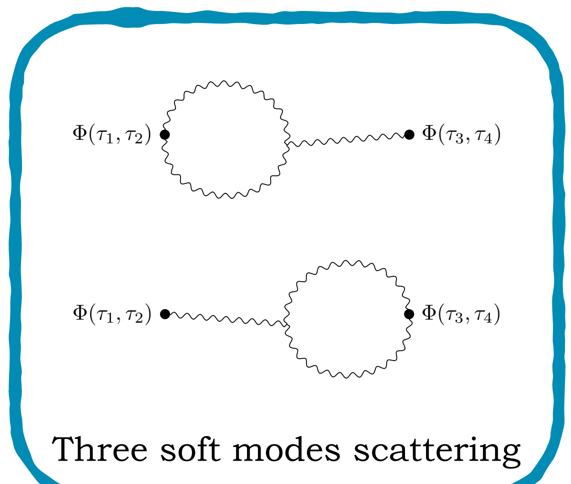
→

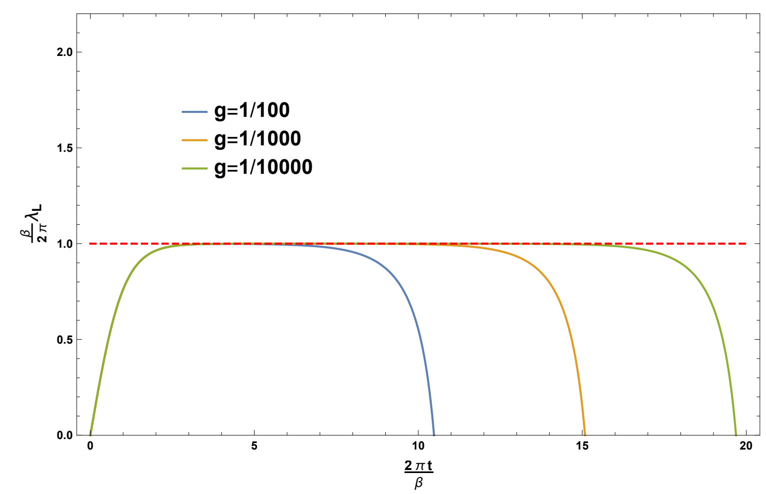
$$\lambda_L = \frac{2\pi}{\beta}\sqrt{\frac{24}{c}|b_0|} \leqq \frac{2\pi}{\beta}$$

Bound on Chaos
[J. Maldacena, S. Shenker, D. Stanford, 1503.01409]

❖ Quantum correction to Chaos [Y. Qi, S. Sin, JY, 1906.00996]







❖ Non-unitary SL(N) higher spin gravity [P. Narayan, JY, 1903.09086]

◆ Higher spin generalization of Schwarzian: soft mode contributions

$$\lambda_L^{(s)} = \frac{2\pi}{\beta}(s-1) \qquad (s = 2, 3, \cdots, N) \quad : \text{violation of bound on chaos}$$

See Yoon in Y306...

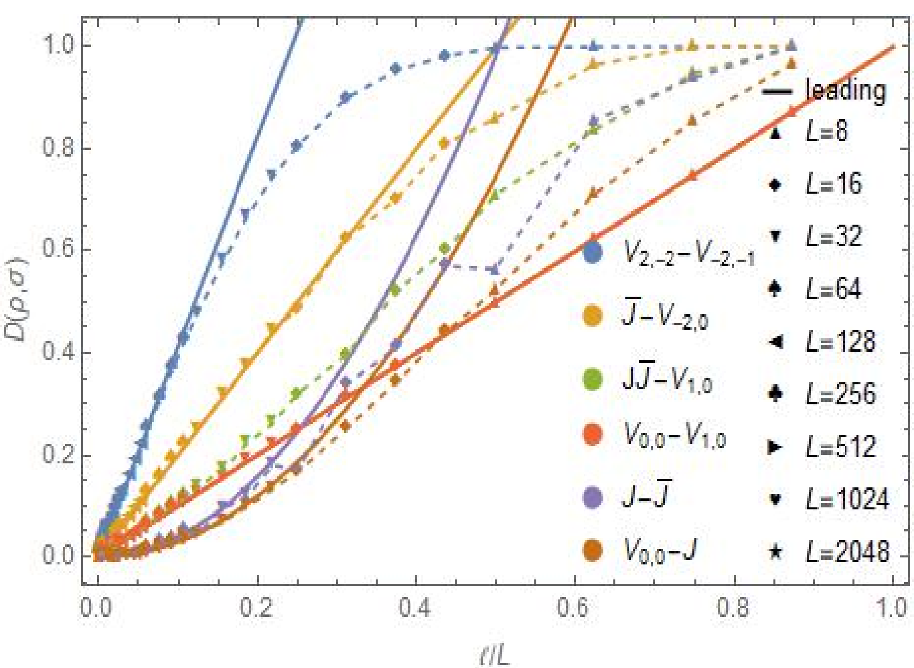
#30

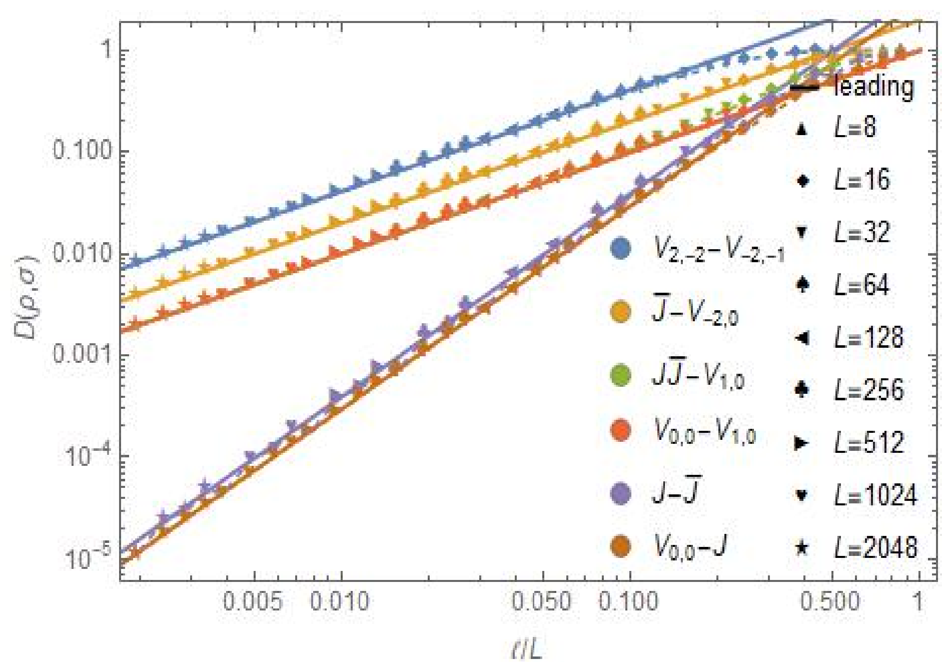
Subsystem Trace Distance in Conformal Field Theory

Jiaju Zhang (张甲举), Paola Ruggiero, Pasquale Calabrese
SISSA and INFN, Italy

Phys. Rev. Lett. 122, 141602 (2019) and work in progress

- We develop the replica trick to calculate the trace distance between two reduced density matrices in two-dimensional conformal field theories
- This method is extensively applied to the lowlying energy eigenstates in free massless boson and fermion theory
- We get leading order short interval expansion of trace distance
- We compare our analytic conformal field theory results with numerical calculations in XX and Ising spin chains finding perfect agreement



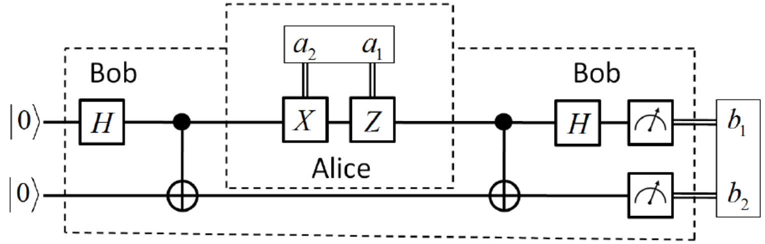


#31

Quantum communication protocols as a benchmark for programmable quantum computers

A.A. Zhukov, E.O. Kiktenko, A.A. Elistratov, W. V. Pogosov, and Yu. E. Lozovik

Superdense coding



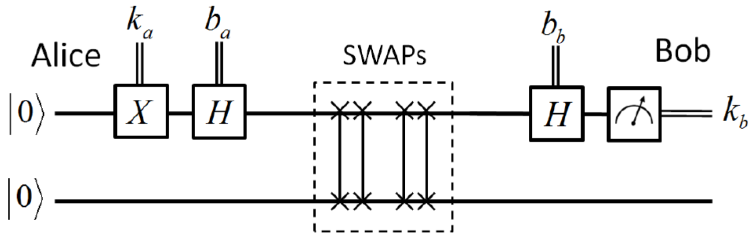
-Deep benchmarking of capabilities of quantum processors:

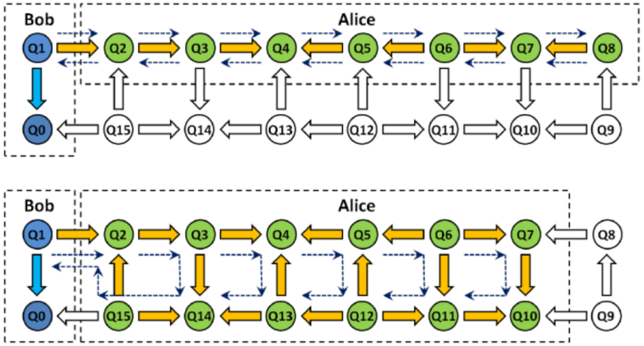
"Quantum communication" between qubits

Simulations of quantum memory imperfections

Robustness with respect to the quantum information transfer

Quantum key distribution BB84





A. A. Zh, E. O. Kiktenko, A. A. Elistratov, W. V. Pogosov, Yu. E. Lozovik, Quantum Information Processing **18**, 31 (2019). →