The Gong Show

The preview show by the 40 poster presenters

#1

YKIS-2016

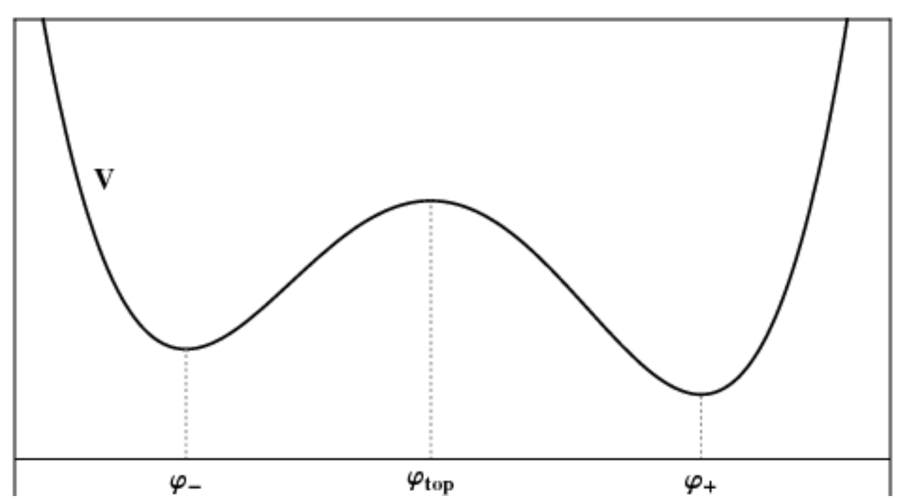
Instantons and Entanglement Entropy

Arpan Bhattacharyya and Ling-Yan Hung
Department of Physics and Center for Field Theory and Particle Physics,
Fudan University

based on work with Charles -Melby Thomson and P.C.H Lau, Arxiv:- 1606.xxxxx

Decay of False Vacuum and Entanglement Entropy

- Entanglement Entropy → How robust is the area Law? →
- How easy (hard) to get volume law for local field theories ???
- Instanton tunneling → crucial to obtain correct ground state
  Classic example is Mexican Hat potential in



- Dilute gas assumption and replica trick give us,

$$S_{EE} = S_0 + \boxed{A(R)KP_1[(1 - logP_n)'|_{n=1} - log(-i\pi\kappa e^{-S_0})]}$$

This is the Instanton correction to the entropy , do an analytic continuation in time, decay rate K enters into the entropy expression

Decay of False Vacuum in spin Chain and Growth of Entanglement Entropy

- Transverse Ising Model:

$$H = -J\sum_i \sigma_i^z \sigma_{i+1}^z + h\Sigma_i \sigma_i^x + b\sum_i \sigma_i^z$$

- Study the time evolution of the wave function which appears like false vacuum

$$|\Psi(t) >= e^{iHT}|0 >$$

$|0 >$ +1 eigenstate of σ_z

- We find the growth of entropy is bounded by the area law

Satisfy Lieb-Robinson Bound

Gauge Theory

- Generic gauge groups the background pure gauge configuration can be classified by different topological sectors.

- These backgrounds cannot be related by small gauge transformation. True vacuum is the sum of all these. $\rightarrow$ θ Vacuum.

- Instanton tunnels between these pure Gauge backgrounds

- θ Vacuum in 2+1d U(1) Gauge theory $S = \int d^3x \frac{1}{4e^2} F^{\mu\nu} F_{\mu\nu}$

- 2+1 d U(1) $\rightarrow$ X-Y model duality

Give us handle how to do the n=1 expansion and the answer for EE matches from both side.

$$\boxed{\begin{aligned} Z_n = \sum_{N=2m} Z_n(N),\ Z_n(N) = \prod_i \xi_i^n \int d^2x\ \exp(-S_n^N), \\ S_n^N \propto \int d^2x \sum_{i,j} q_i q_j G_n(x_i, x_j) \end{aligned}}$$

Modelling θ -Vacuum

- One more classic example is 1+1 dimensional Schwinger model:

$$S_{schwinger} = \int d^2x \, \bar{\psi} \gamma^{\mu} (i\partial_{\mu} - e\, A_{\mu}) \psi - \frac{1}{4} F^{\mu\nu} F_{\mu\nu}$$

- θ Vacuum (in temporal Gauge) :

$$|\theta >= \sum_N \exp^{iN\theta} f_0(N,\lambda) \prod_{n>0} exp^{-t_n(\tilde{j}^{\dagger}_{+n}\tilde{j}^{\dagger}_{+n} - \tilde{j}_{-n}\tilde{j}_{-n})} |N >$$

$$\tilde{j}_{n,\pm} = \cosh \gamma_n j_{n,\pm} + \sinh \gamma_n j^{\dagger}_{n,\pm} \, , j_{\pm} = \bar{\psi} \gamma_{\pm} \psi$$

Bogoliubov transformation

- Too complicated , we will consider a toy model where we just focus on the (weighted) sum of the Fermi-surfaces.

$$|\Psi >= \sum_{N=1}^{L} f(N,\lambda) \prod_{k_i}^{N} c^{\dagger}_{k_i} |0 >$$

$$c_{k_1} = \frac{1}{\sqrt{L}} \sum_j c_j e^{-ik_i x_j} \, , c_j = (\prod_{i<j} \sigma^z_i) \sigma^+_j$$

- Entanglement entropy for this case cannot scale as “Volume”.

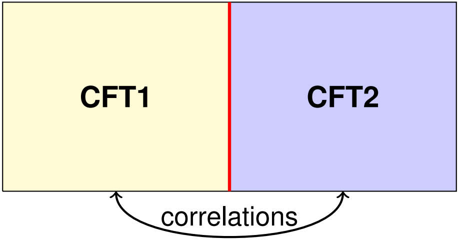
#2

Entanglement Entropy and Conformal Interfaces

Enrico Brehm, Ilka Brunner, Daniel Jaud, Cornelius Schmidt-Colinet

Arnold Sommerfeld Center, Ludwig Maximilian Universität München

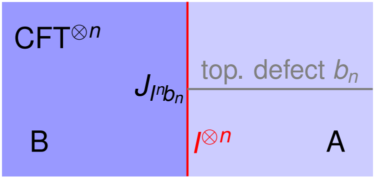
June 15th 2016



Measure of choice: **Entanglement Entropy**

$$S_A = -\mathrm{Tr}\,\rho_A \log \rho_A = -\frac{\partial}{\partial n}\mathrm{Tr}\rho_A^n\,.$$

Method:



Result:

$$S_I = \sigma_I \frac{c}{3}\log L + s(I)\,.$$

#3

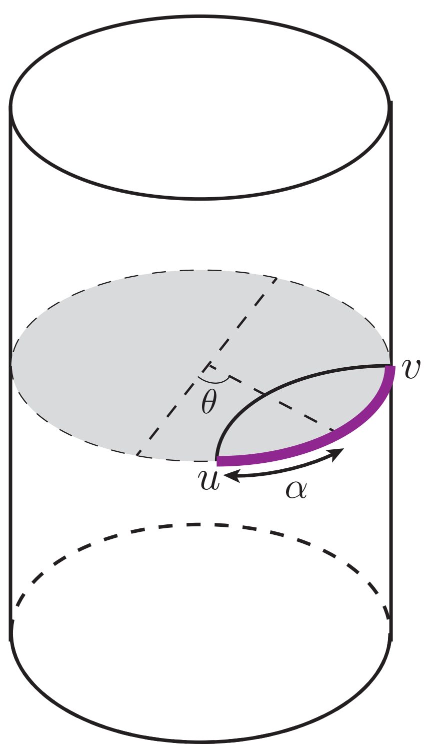
Equivalence of Emergent de Sitter Spaces from Conformal Field Theory

Claire Zukowski

C. T. Asplund, N. Callebaut, CZ [1604.02687]

Two proposals for a dS space emergent from entanglement entropy:

1) Kinematic Space



KS = Space of boundary intervals in CFT_2 /spacelike Ryu-Takayanagi geodesics on a bulk slice of AdS_3

$$ds^2 = \frac{\partial^2 S(u,v)}{\partial u \partial v} du dv$$

$\Rightarrow$ Global dS_2

Czech, Lamprou, McCandlish, Sully (2015a)

2) Auxiliary de Sitter Proposal

Modular Hamiltonian for ball-shaped regions for CFT_d in vacuum:

$$H_{\mathrm{mod}} = 2\pi \int_B \mathcal{P} T_{00}$$

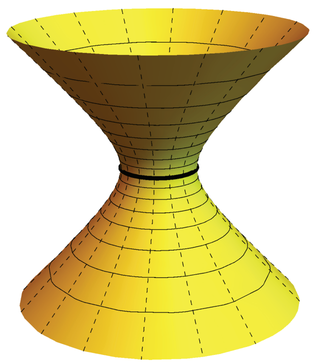
$\mathcal{P} =$ boundary-to-bulk dS_d propagator

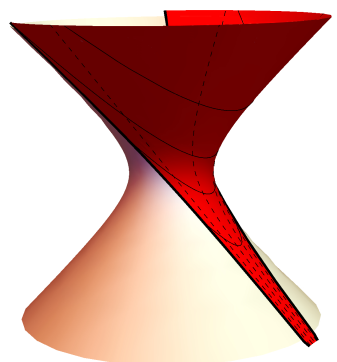
$\Rightarrow \delta S = \langle H_{\mathrm{mod}} \rangle$ satisfies a dS Klein-Gordon equation

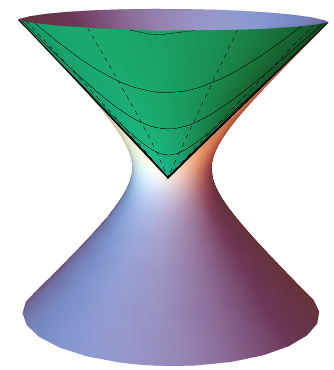
de Boer, Heller, Myers, Neiman (2015)

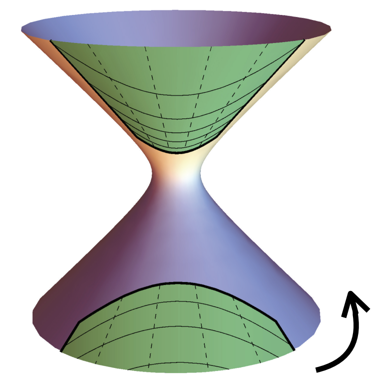
Our Results

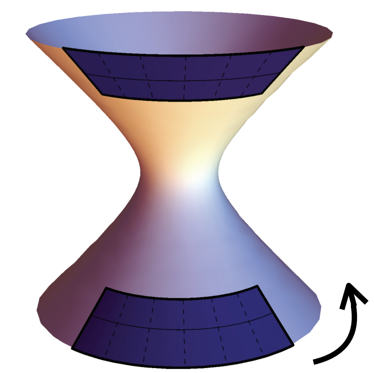
Goal: Provide support for the equivalence of these emergent spacetimes in the vacuum case and beyond


Pure AdS


Poincaré Patch


BTZ String


BTZ BH


Con. Sing.

Our Results:

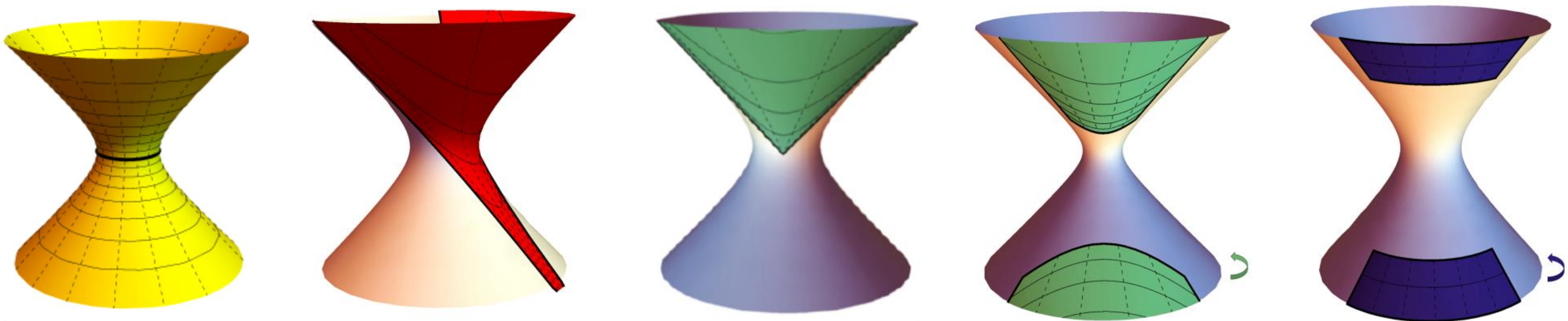
- *Thermal Case*: KS for BTZ black string is the hyperbolic patch of dS_2. Perturbations of EE satisfy a wave equation on KS.
- *Quotient Spaces*: For e.g. BTZ black hole/conical singularity, phase transitions in EE introduce defects in KS.
- *Causal Structure*: KS of locally AdS_3 spaces is generically globally hyperbolic.

Equivalence $\Leftrightarrow$ Modular Hamiltonian from EE?

Kinematic space K (1.0) = space of CFT_2 intervals / AdS_3 geodesics

[Czech, Lamprou, McCandlish, Sully JHEP 1510 (2015) 175]

K of global AdS_3 = global dS_2 | K of Poincare AdS | K of BTZ black string | K of BTZ black hole | K of conical star



K = auxiliary de Sitter of

[de Boer, Heller, Myers, Neiman Phys.Rev.Lett. 116 (2016) no.6, 061602]

$\Downarrow$

EE perturbations propagate on K

K of quotiented geometries raises questions on propagating fields on K

[Asplund, NC, Zukowski 1604.02687]

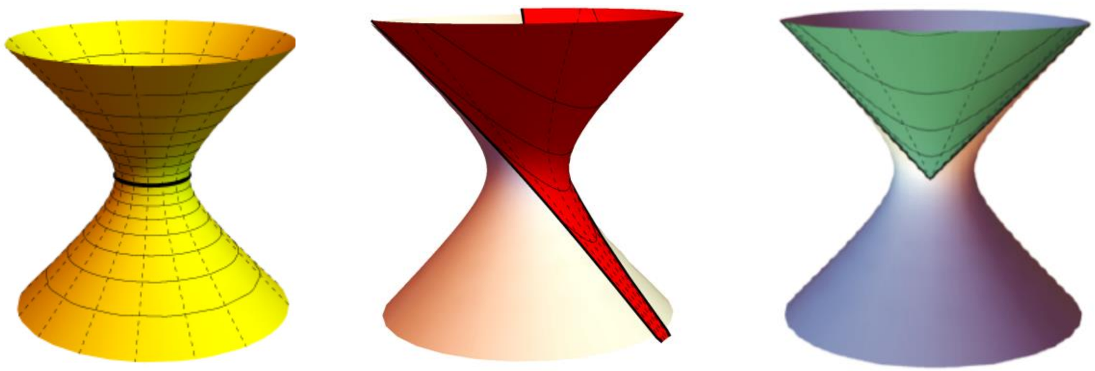
Kinematic space K (1.0) = space of CFT_2 intervals / AdS_3 geodesics

[Czech, Lamprou, McCandlish, Sully JHEP 1510 (2015) 175]

K of global AdS_3 = global dS_2

K of Poincare AdS

K of BTZ black string



K = auxiliary de Sitter of

[de Boer, Heller, Myers, Neiman Phys.Rev.Lett. 116 (2016) no.6, 061602]

$\Downarrow$

EE perturbations propagate on K

$\longrightarrow$

K = auxiliary dS for any locally AdS_3 geometry, by recognizing K as Liouville metric with the EE the Liouville field

[NC, Verlinde - in preparation]

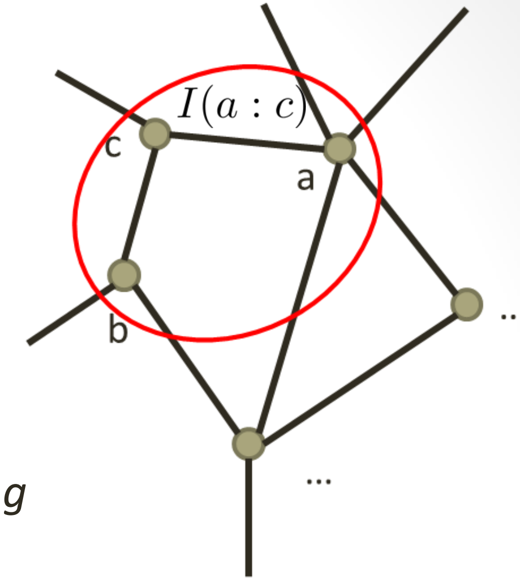
#4

Emergent Geometry from Redundancy-Constrained States and Bulk Entanglement Gravity

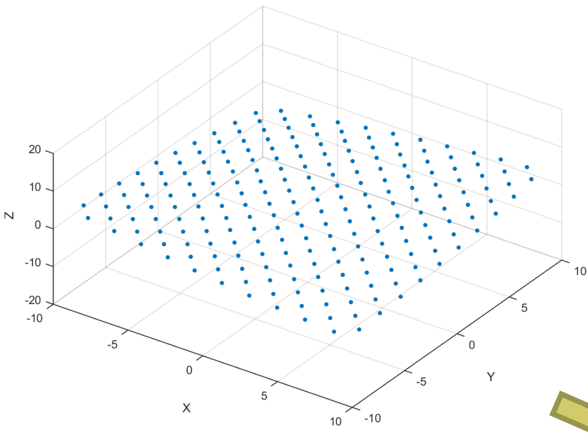
ChunJun Cao and Sean Carroll,
California Institute of Technology
Prepared for YKIS 2016

$$|\psi\rangle \in \mathcal{H} = \bigotimes_i \mathcal{H}_i$$

Entanglement data

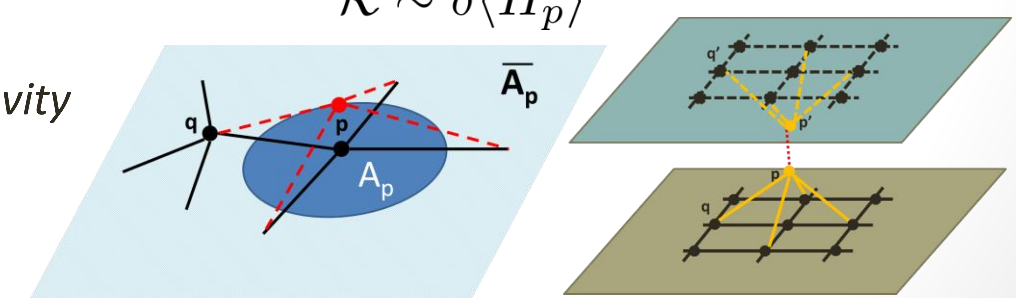


Embedding manifold



$$\mathcal{R} \sim \delta\langle H_p \rangle$$

Entanglement perturbation and gravity



#5

Entanglement Entropy in a Holographic Kondo Model

Mario Flory

Max-Planck-Institut für Physik

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

MAX-PLANCK-GESELLSCHAFT

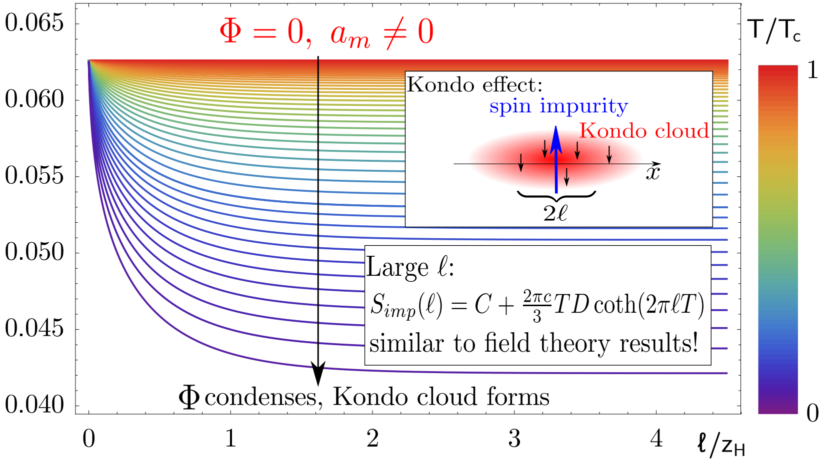
Quantum Matter, Spacetime and Information

YITP, 15.06.2016

Based on 1410.7811 and 1511.03666

Entanglement entropy in the Kondo effect

$$\frac{3}{c}S_{imp}(\ell) \equiv \frac{3}{c}S(\ell)\Big|_{\text{Impurity present}} - \frac{3}{c}S(\ell)\Big|_{\text{Impurity absent}}$$



#6

A holographic dual to the Bose-Hubbard Model

- Bose-Hubbard model as the effective theory on an optical lattice, including the hopping term + Short-range repulsive interactions U
  - The extension to the *SU(N)* Bose-Hubbard model

Conjecture of *MF-Harrison-Karch-Meyer-Paquette, JHEP04(2015)068*

SU(N) Bose-Hubbard model

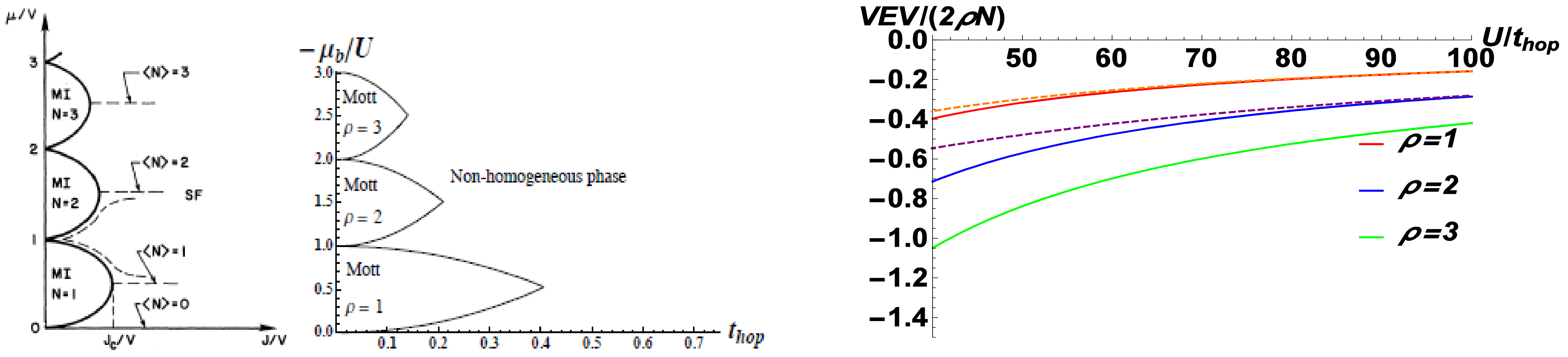
2d gravity on the AdS_2 hard wall

$$H = -w\sum_{<ij>}(b_{ai}{}^{\dagger}b_{aj} + b_{aj}{}^{\dagger}b_{ai})$$

$$-\mu\sum_{j} n_j + \frac{U}{2}\sum_{j} n_j(n_j - 1),\; n_i = b_{ai}^{\dagger}b_{ai}$$

- To compute the VEV of the hopping term in both sides of the duality concretely and compare them, *Work in progress of MF-Meyer-Sumiran-Tezuka*

Main results and comparision



(a) (b) (c)

- (b): Realizing the lobe-shaped phase structure from the gravity dual
  - Finding zero modes at the cusp around $t_{hop}=0$
- (c): Comparision of dF/dt_{hop}: the result of $SU(N_c)$ Bose-Hubbard model fits the result of the gravity dual at small hopping well (Dashed lines are the field theory result)

#7

Fractional quantum Hall states of dipolar fermions in a strained optical lattice

Hiroyuki Fujita, ISSP. Univ. Tokyo

Aim: Quantum simulation of strongly entangled phase of matter

Landau levels — **Synthetic magnetic field in a strained honeycomb optical lattice**

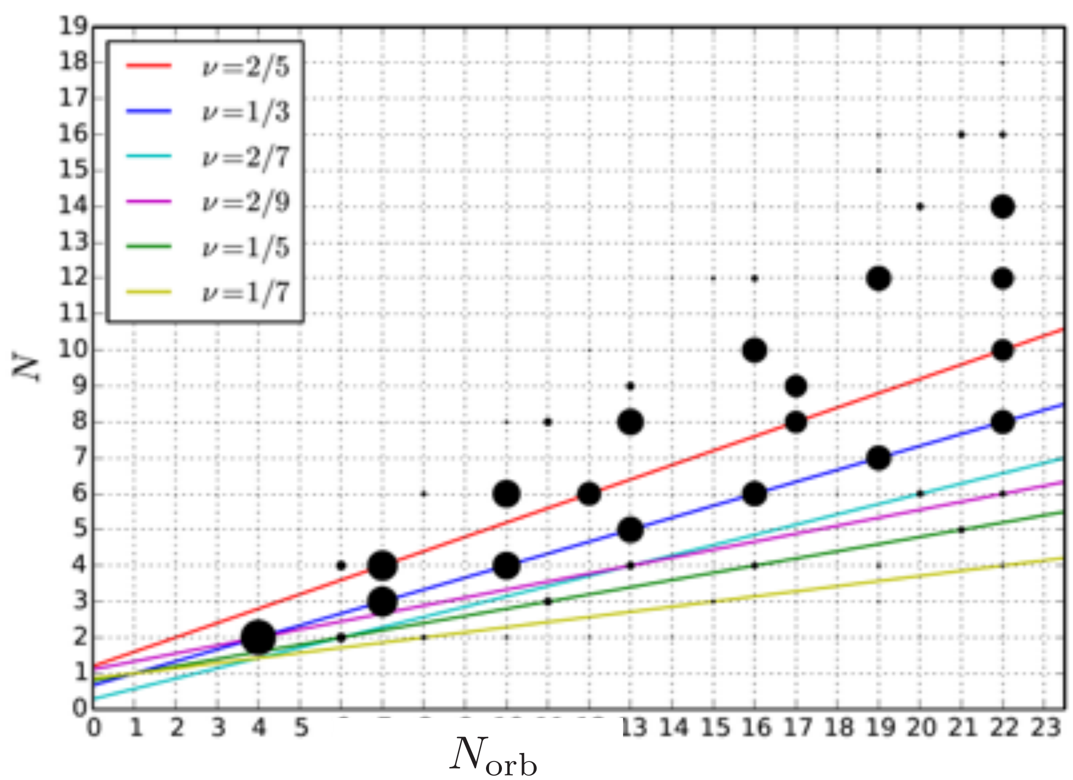
Correlation — **Fermionic dipolar molecule e.g. NaRb**

→ Realization of FQHE states in ultra-cold gases?

Method: Exact diag. in a spherical geometry in lowest LL

Result:

<u>Various valley-polarized FQHE states found</u>



$\tilde{\nu}$	$N=\tilde{\nu}(N_{\mathrm{orb}}+\delta)$	p	n
1/3	$N=\frac{1}{3}(N_{\mathrm{orb}}+2)$	1	1
2/5	$N=\frac{2}{5}(N_{\mathrm{orb}}+3)$	1	2
1/5	$N=\frac{1}{5}(N_{\mathrm{orb}}+4)$	2	1
1/7	$N=\frac{1}{7}(N_{\mathrm{orb}}+6)$	3	1
2/7	$N=\frac{2}{7}(N_{\mathrm{orb}}+1)$	2	−2
2/9	$N=\frac{2}{9}(N_{\mathrm{orb}}+5)$	2	2

$$N=\frac{n}{2np+1}(N_{\mathrm{orb}}+2p+n-1)$$

Energy scale estimation for $\nu=\frac{1}{3}$ Laughlin state of $^{23}\mathrm{Na}^{87}\mathrm{Rb}$

Discussion on its experimental realization

#8

Shape Dependence of Holographic Rényi entropies.

Damián A. Galante (UWO/PI)
Work in progress in collaboration with L. Bianchi, S. Chapman, X. Dong, M. Meineri and R. Myers

Lots of conjectures have been made recently about universal features of Rényi entropies of deformed entangling surfaces...

For 4d CFTs

$$f_b(n) = f_c(n)$$

Cone Contributions to Rényi Entropies

$$\sigma_n^{(d)} \propto \frac{h_n}{n-1}$$

Displacement conjecture in general dimensions

$$C_D(n) = d\Gamma\left(\frac{d+1}{2}\right)\left(\frac{2}{\sqrt{\pi}}\right)^{d-1} h_n$$

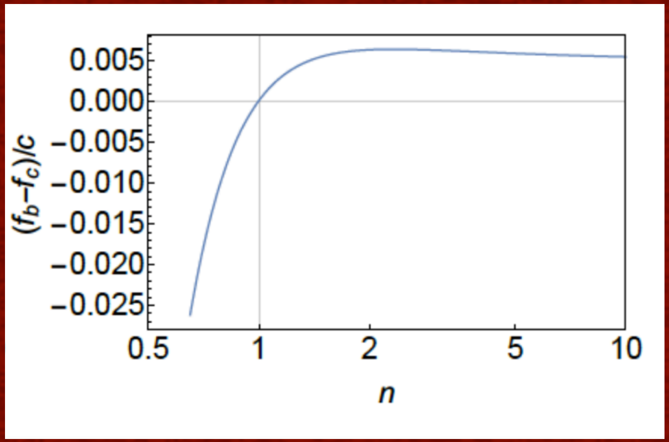
There has been a proof around n=1 [Faulkner, Leigh, Parrikar], but for general n...

Shape Dependence of Holographic Rényi entropies.

Damián A. Galante (UWO/PI)
Work in progress in collaboration with L. Bianchi, S. Chapman, X. Dong, M. Meineri and R. Myers

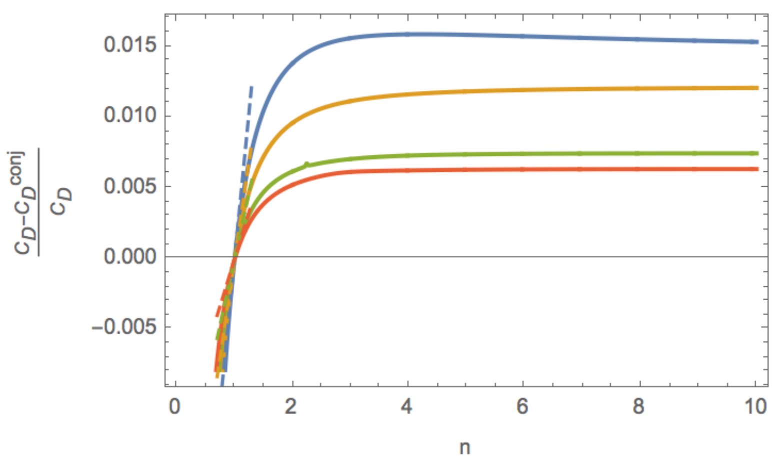
In 4d holographic CFTs

$$f_b(b) \neq f_c(n)$$



[X. Dong, 2016]

In holographic CFTs in d dimensions



What is C_D? How to compute it in holographic theories?
What is the result? How different is it from the conjecture?

Come see my poster!

#9

Dyonic extremal Black hole entropy for $\mathcal{N} = 8$ gauged supergravity

Prieslei Goulart - IFT/UNESP - Sao Paulo, Brazil - MPI - Munich, Germany

- Motivation: obtain the black hole entropy for supergravity theories with a non-trivial dilaton potential;
- Sen's entropy function:
  Near horizon metric is $AdS_2 \times S^2$:

$$ds^2 = v_1 \left(-r^2 dt^2 + \frac{dr^2}{r^2} \right) + v_2 (d\theta^2 + \sin^2\theta d\phi^2), \tag{1}$$

where the constants v_1 and v_2 are the AdS_2 radius and the S^2 radius respectively.
Entropy function:

$$\mathcal{E}(\vec{u}, \vec{v}, \vec{e}, \vec{q}, \vec{p}) \equiv 2\pi [e_A q^A - \int d\theta d\phi \sqrt{-\det g} \mathcal{L}]. \tag{2}$$

Attractor equations:

$$\frac{\partial \mathcal{E}}{\partial u_s} = 0, \quad \frac{\partial \mathcal{E}}{\partial v_1} = 0, \quad \frac{\partial \mathcal{E}}{\partial v_2} = 0, \quad \frac{\partial \mathcal{E}}{\partial e_A} = 0\ , \tag{3}$$

At the extremum (3) the entropy function is the black hole entropy:

$$S_{BH} = \mathcal{E}(\vec{u}, \vec{v}, \vec{e}, \vec{q}, \vec{p}). \tag{4}$$

- We obtain the dyonic black hole entropy $\mathcal{N} = 8$ gauged supergravity:

$$S = \int d^4x\sqrt{-g}\left[R - \frac{3}{8}\left(\sum_{I=1}^{4}(\partial_\mu\lambda_I)^2 - 2\sum_{I<J}\partial_\mu\lambda_I\partial^\mu\lambda_J\right) - \frac{1}{4}\sum_{I=1}^{4}X_I^2(F_{\mu\nu}^I)^2 - V\right], \tag{5}$$

$$F_{\mu\nu}^I = \partial_\mu A_\nu^I - \partial_\nu A_\mu^I, \quad V(X) = -\frac{g^2}{4}\sum_{I<J}\frac{1}{X_I X_J}, \quad X_1X_2X_3X_4 = 1. \tag{6}$$

- The entropy is written as

$$\mathcal{E} = 2\pi\left(\sum_{I=1}^{4} q^I p_I\right)\left[\frac{1}{2}\left(1 + \sqrt{1 - \frac{g^2}{2}\left(\sum_{I=1}^{4} q^I p_I\right)\left(\sum_{J<K}\sqrt{\frac{p_J p_K}{q^J q^K}}\right)}\right)\right]^{-1/2}. \tag{7}$$

- The entropy can also be written as

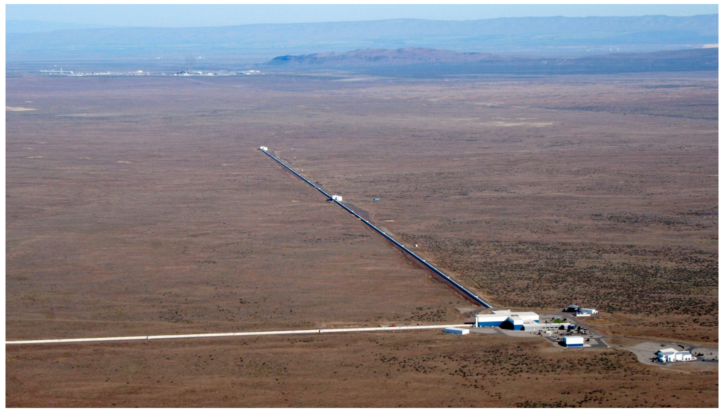
$$\mathcal{E} = \frac{1}{2}\left(\sum_{I=1}^{4} q^I p_I\right)\left(\frac{q^1q^2q^3q^4}{p^1p^2p^3p^4}\right)^{1/4}. \tag{8}$$

- We also how the entropy changes under electric-magnetic duality.

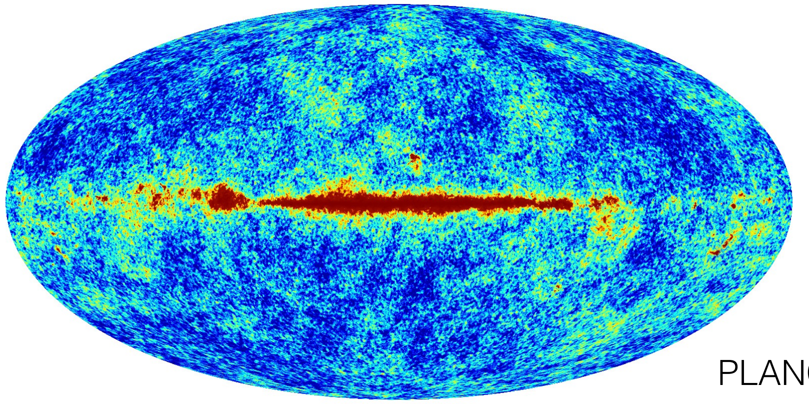
#10

String theory is not even wrong?

Not really; we will make it FALSIFIABLE!



LIGO



PLANCK

Today we propose yet another approach:

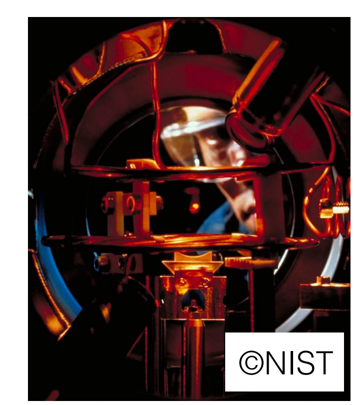
an experimental realization of a quantum black hole

Super Yang-Mills $\longleftrightarrow$ IIA/IIB-string
M-theory
(BH, black brane)

Sachdev-Ye-Kitaev model $\longleftrightarrow$ BH in AdS_2

Make them from atoms and lasers!

Experimental Quantum Gravity with Cold Atoms



I. Danshita, M. Hanada, M. Tezuka

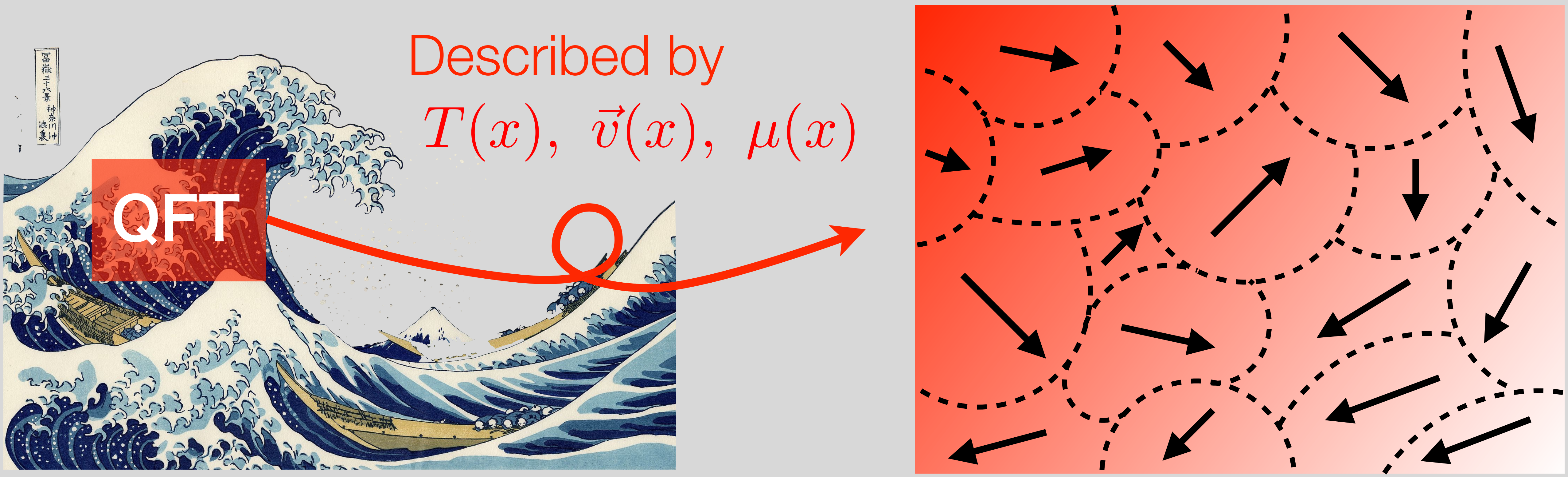
Let's make a black hole in your lab and see how it behaves!

#11

Hayata, Hidaka, **MH**, Noumi, Phys. Rev. D **92**, 065008

MH in preparation (2016)

Emergent curved spacetime from locally thermalized matter



Masaru Hongo

iTHES Research group, RIKEN

Quantum Matter, Spacetime and Information, 2016/6/15, Kyoto University,

Thermal Field Theory

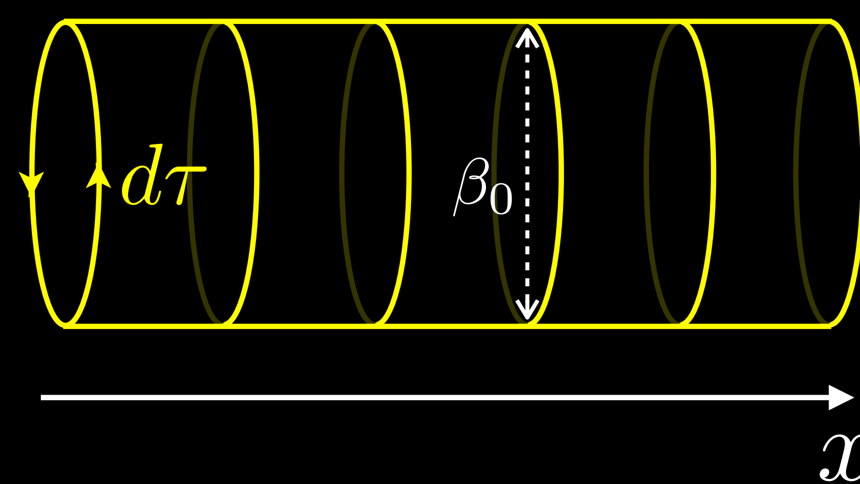
Thermodynamics β_0

$$T = \text{const.}$$

Path int.

Thermal Field Theory

(Matsubara, 1955)



QFT in the flat spacetime with radius β_0

Gibbs distribution: $\hat{\rho}_G = \dfrac{e^{-\beta(\hat{H}-\mu\hat{N})}}{Z} = e^{-\beta(\hat{H}-\mu\hat{N})-\Psi[\beta,\nu]}$

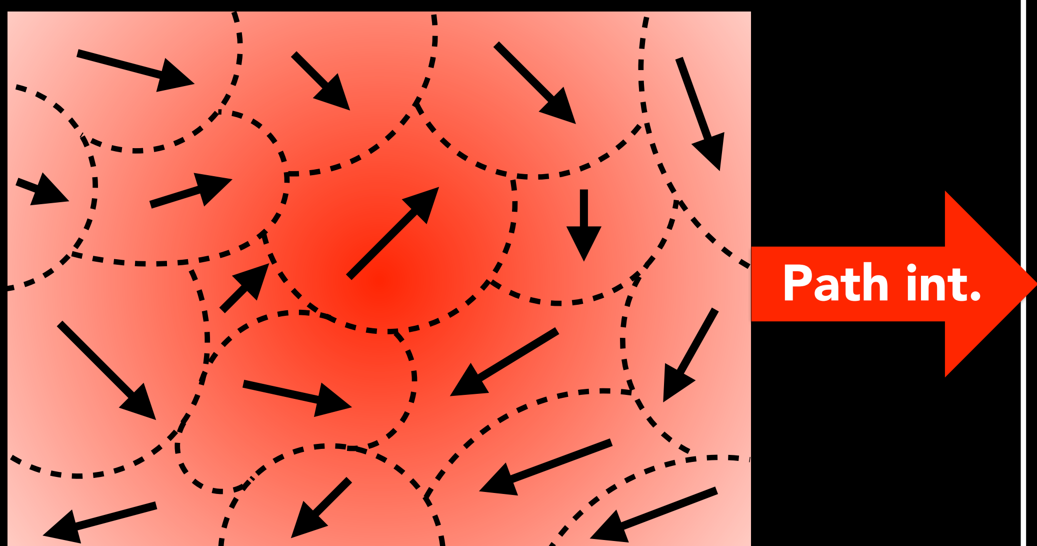
Thermodynamic potential with Euclidean action

$$\Psi[\beta,\nu] = \log \mathrm{Tr}\, e^{-\beta(\hat{H}-\mu\hat{N})} = \log \int d\varphi \langle \pm\varphi | e^{-\beta(\hat{H}-\mu\hat{N})} | \varphi \rangle$$

$$= \log \int_{\varphi(\beta)=\pm\varphi(0)} \mathcal{D}\varphi\, e^{+S_E[\varphi]}, \quad S_E[\varphi] = \int_0^\beta d\tau \int d^3x\, \mathcal{L}_E(\varphi, \partial_\mu\varphi)$$

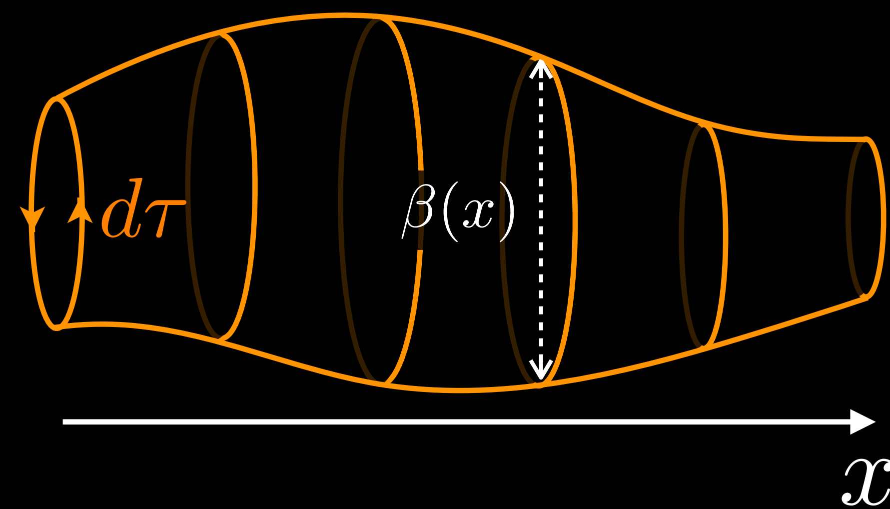
Local Thermal Field Theory

Hydro $\{\beta(x),\ \vec{v}(x)\}$



Local Thermal Field Theory

[Hayata-Hidaka-**MH**-Noumi '15]



QFT in the "curved spacetime" with "metric"

$$\tilde{g}_{\mu\nu} = \tilde{g}_{\mu\nu}(\beta, \vec{v})$$

$$\Psi[\bar{t};\lambda] \equiv \log \mathrm{Tr} \exp\left[\int d\Sigma_{\bar{t}\nu}\left(\beta^{\mu}(x)\hat{T}^{\nu}{}_{\mu}(x) + \nu(x)\hat{J}^{\nu}(x)\right)\right]$$

$\Psi[\lambda]$ **is written in terms of QFT in curved spacetime**

$$ds^2 = -e^{2\sigma}(d\tilde{t} + a_{\bar{i}})dx^{\bar{i}} + \gamma'_{\bar{i}\bar{j}}dx^{\bar{i}}dx^{\bar{j}}$$

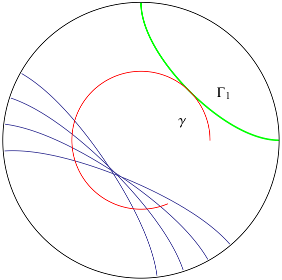
Symmetry = Spatial diffeomorphism + Kaluza-Klein gauge

Consistent with [Banerjee et al.(2012), Jensen et al.(2012) …]

#12

Crofton's formula

Czech etal. 2015



$$\boxed{\frac{\sigma(\gamma)}{4G} = \frac{1}{4}\int_{\gamma\cap\Gamma\neq\varnothing} N(\gamma\cap\Gamma)\,\epsilon_{\mathcal{K}}}$$

The length $\sigma(\gamma)$ of a curve γ can be expressed in terms of an integral over the geodesics Γ that have nonvanishing intersection number $N(\gamma\cap\Gamma)$ with γ

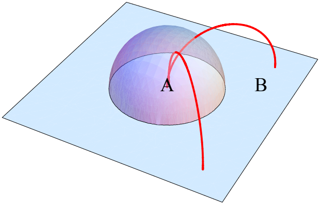
The measure $\epsilon_{\mathcal{K}}$ is given by the second derivative of the entanglement entropy

$$\boxed{\epsilon_{\mathcal{K}}(u,v) = \frac{\partial^2 S(u,v)}{\partial u \partial v}\mathrm{d}u \wedge \mathrm{d}v}$$

Hence we can obtain the geometry from the entanglement structure of the field theory on the boundary

Kinematic space of geodesics in general dimensions

XH and Lin 2015



Crofton's formula in higher dimensions:

$$\sigma_d(M^d) \sim \int_{M^{d-1}\cap\Gamma\neq\varnothing} N(M^d\cap\Gamma)\,\epsilon_{\mathcal{K}}$$

which says that the area is equal to flux of geodesics

$$\epsilon_{\mathcal{K}} = \frac{1}{4G}\det\left[\frac{\partial^2 S(\vec{x}_1,\vec{x}_2)}{\partial\vec{x}_1\partial\vec{x}_2}\right]\prod_{i=1}^{d-1}\mathrm{d}x_2^i\wedge\mathrm{d}x_1^i$$

- The volume form follows from second derivative of S and is a new type of measure of two-point correlation (entanglement contour)
- S is no longer related to entropy even though it can be computed from field theory

#13

Coupled Wire Construction and generalized Wilson line

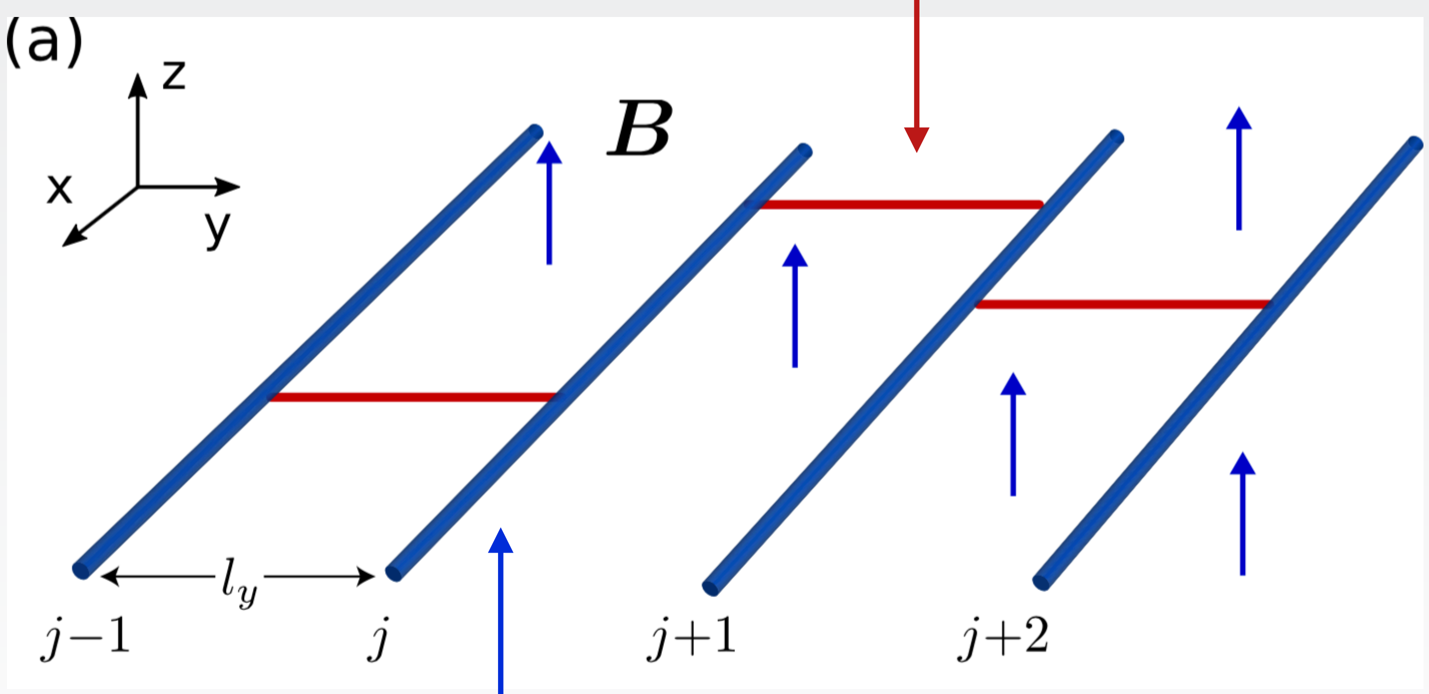
YKIS2016

Yukihisa Imamura and Keisuke Totsuka (arXiv:1605.09235)

Coupled Wire Construction :

A new method of systematically constructing topological phases

many-body hopping interaction



CFT (Luttinger liquid)

(Abelian)
Laughlin state
chiral spin liquid

(Non-Abelian)
Moore-Read state
Read-Rezayi state
etc.

Coupled Wire Construction and generalized Wilson line

YKIS2016

Yukihisa Imamura and Keisuke Totsuka (arXiv:1605.09235)

The bulk theory of the Laughlin state
= the Chern-Simons gauge theory

$\longrightarrow$ **How emerging in the coupled wire construction?**

The ground state has some redundancy
related to a gauge and a chiral transformation

generalized Wilson line : $$\bar{\psi}_{j+1} \exp\left[i \int_{ja}^{(j+1)a} dy \left(\frac{e}{\hbar} A_y + \underline{a_y \gamma_5} \right) \right] \psi_j$$

$\uparrow$

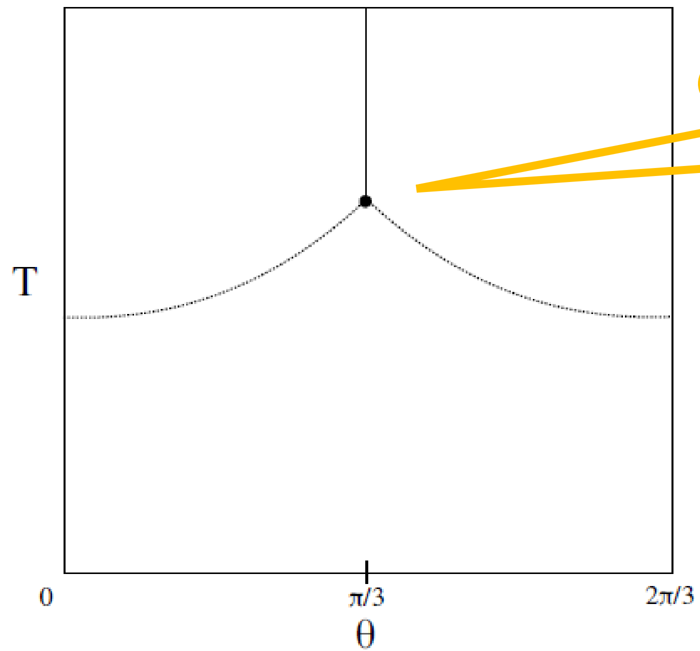
Chern-Simons gauge field

#14

Topological phase transition in QCD
described by using imaginary chemical potential

<u>K.K.</u> and A. Ohnishi, PLB 750 (2015) 282.
<u>K.K.</u> and A. Ohnishi, arXiv: 1602.06037, to be published in PRD.

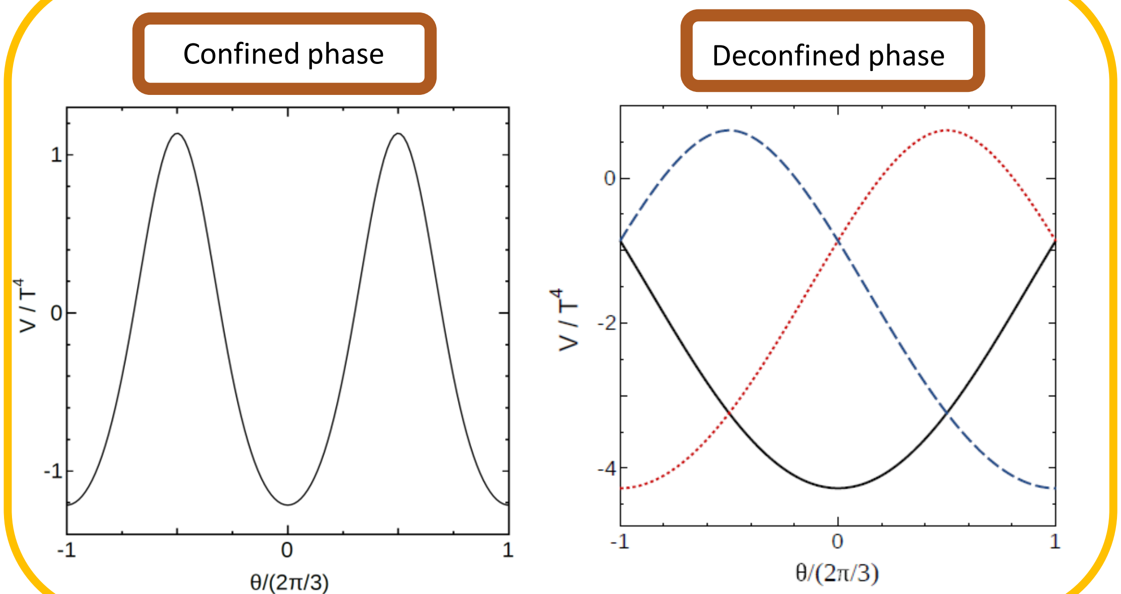
We propose a new determination of the confinement-deconfinement transition in QCD



The Roberge-Weiss endpoint would define the **deconfinement temperature**

In this determination,
the deconfinement transition
can be interpreted as
the **topological phase transition**

Effective potential



This determination may have direct relations with the entanglement entropy and the Uhlmann phase

#15

Distinguishability of countably many states

Ryuitiro Kawakubo and Tatsuhiko Koike, Department of Physics, Keio University

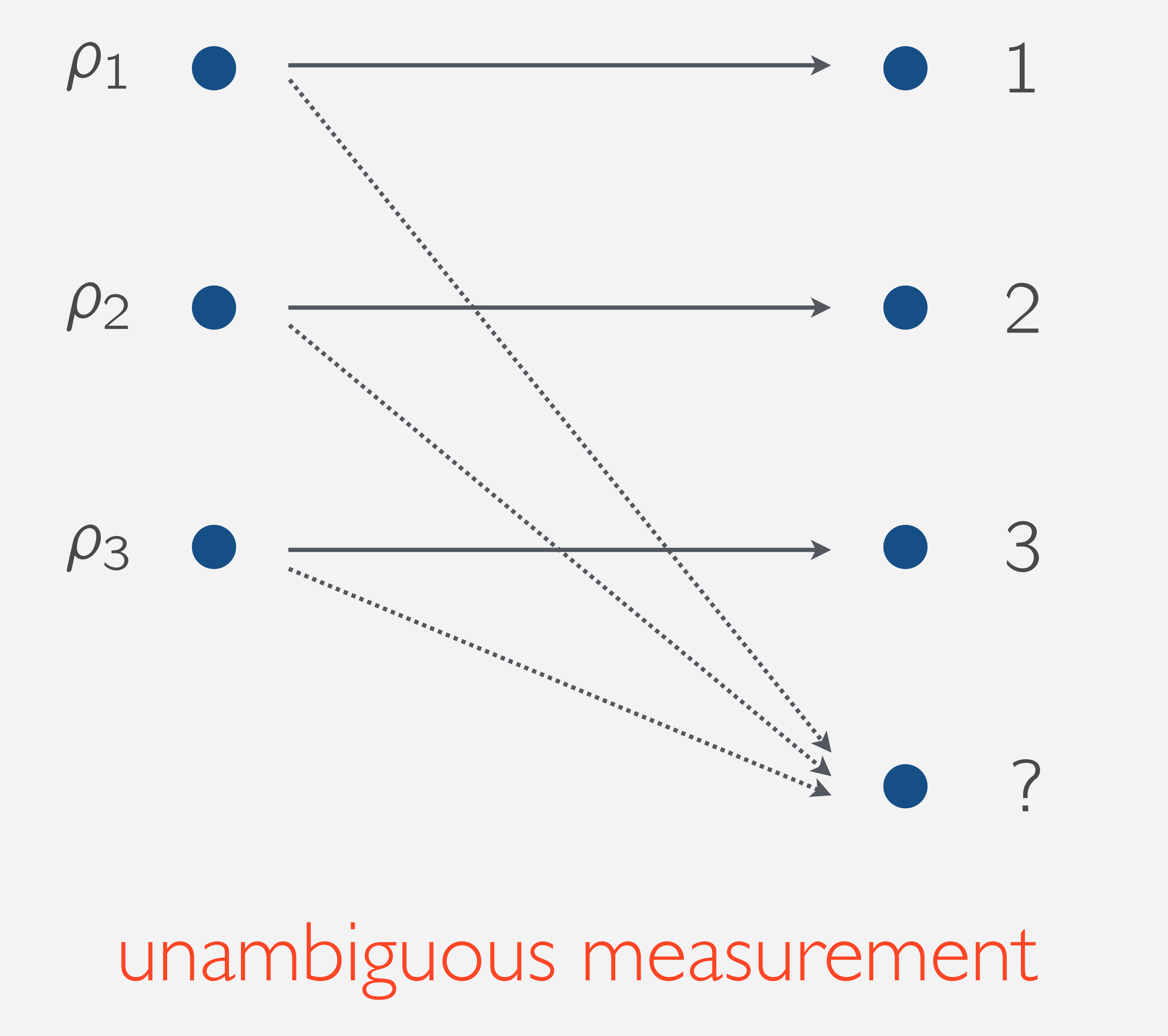
Theme:

State discrimination (We want to distinguish each state in a given set of states).

Problem:

What kind of states can be distinguishable by a single measurement?
More precisely, in our discussion distinguishability of states is to be understood as the possibility of an unambiguous measurement on them.

- An unambiguous measurement is allowed to answer "?" or "do not know".
- An unambiguous measurement distinguishes the inputs *with certainty* unless "?" is detected.



✳ Condition for distinguishability

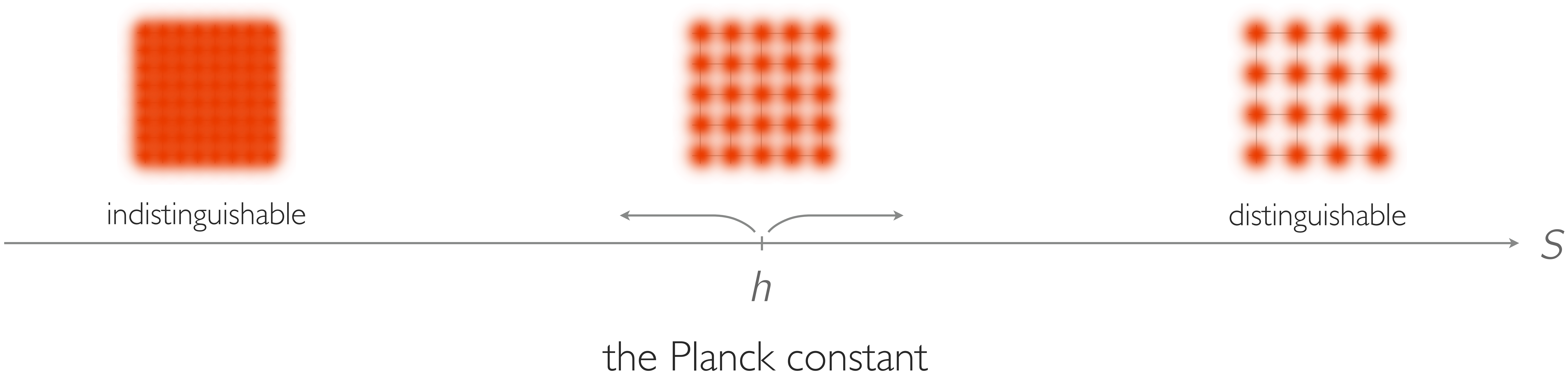
We obtained
countable pure states to be distinguishable.

Distinguishability of countably many states

Ryuitiro Kawakubo and Tatsuhiko Koike, Department of Physics, Keio University

✳ Distinguishability of von Neumann lattices

A von Neumann lattice is a family of states which corresponds to the lattice in the classical phase space. The distinguishability of a von Neumann lattice depends only on the area of its fundamental region S. It is indistinguishable when S is sufficiently small and distinguishable when S is sufficiently large. The threshold is exactly the Planck constant, which is the unit of area of the phase space as in Bohr-Sommerfeld quantum condition.



#16

#17

Holographic Entanglement Entropy of Anisotropic Minimal Surfaces in LLM Geometries

YKIS2016 Quantum Matter, Spacetime and Information
June 13-June 17, 2016 YITP, Kyoto University, Japan

In collaboration with Chanju Kim, O-Kab Kwon

Based on arXiv1605.00849 (accepted in PLB)
Previous related works
Phys.Rev. D90 (2014) 4, 046006 ,
Phys.Rev. D90 (2014) 12, 126003
(with O. Kwon, C. Park and H. Shin.)

Kyung Kiu Kim
(Yonsei University)

ABJM $\sim$ $AdS_4 \times S^7/Z_k$

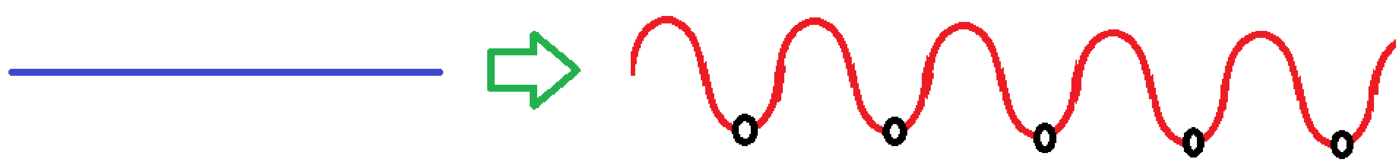
ABJM + mass term → mass deformed ABJM theory

mABJM $\sim$ A Class of LLM solutions
with SO(2,1)×SO(4)×SO(4)
(Asymptotically $AdS_4 \times S^7/Z_k$)

$$ds^2 = |G_{tt}|(-dt^2 + dw_1^2 + dw_2^2) + G_{xx}\left(dx^2 + dy^2\right) + G_{\theta\theta} ds^2_{S^3/\mathbb{Z}_k} + G_{\tilde{\theta}\tilde{\theta}} ds^2_{\tilde{S}^3/\mathbb{Z}_k},$$

- Vacuum structure

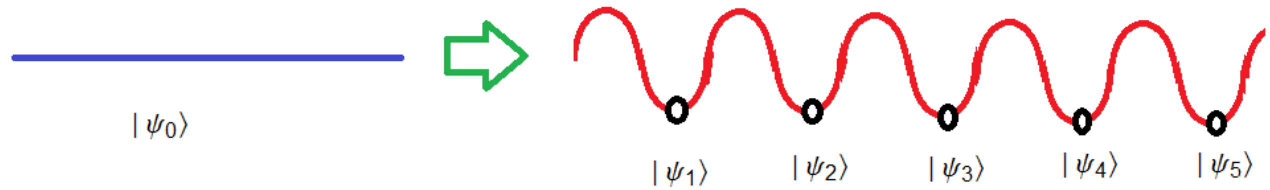
Continuous Vacua → Discrete Vacua



- Entanglement Entropy ?

$\rho = |\psi\rangle\langle\psi|$ $\qquad$ $s = \mathrm{Tr}\,(-\rho_A \log \rho_A)$

- An infinite number of entanglement entropies



- We consider all the entanglement entropies corresponding to all the vacua through a holographic approach(Ryu-Takayanagi Formula).
- For small mass deformation

$$S_{\rm disk} = \frac{\pi^5 R^9}{24 G_N k}\left\{\frac{l}{\epsilon} - 1 - \mu_0^2 l^2\left[\frac{4}{3} + \frac{1}{24}(C_3 - 3C_1C_2 + 2C_1^3)^2\right]\right\} + \mathcal{O}(\mu_0^3).$$

- This result should correspond to the corresponding field theory calculation with small mass perturbation.

$$\rho_i = |\psi_i\rangle\langle\psi_i| \qquad s = \mathrm{Tr}\,(-\rho_i \log \rho_i)$$

- There are many interesting structures(Droplet picture, Yong diagam, H c-theorem). Please visit my poster presentation ! Thank you !

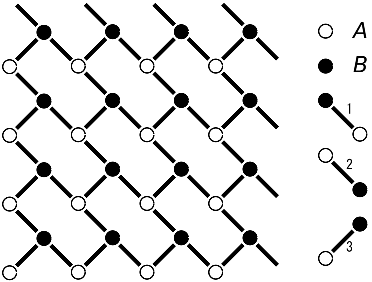
#18

Dynamic correlation of Kitaev's honey-comb model

Shinji Koshida

Department of Basic Science, The University of Tokyo

June 15, 2016

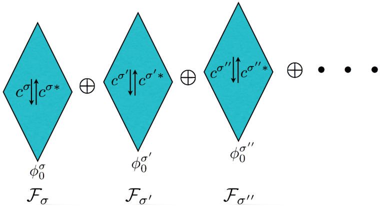


$$H_{\mathrm{Kit}} = -\sum_{\mu=1,2,3} J_\mu \sum_{(x,y)\in B^\mu_\Lambda} S^\mu_x S^\mu_y.$$

- By mapping the Kitaev's honey-comb model to Majorana fermions coupled to $\mathbb{Z}_2$-gauge fields,

$$\tilde{H} = \frac{i}{4} \sum_{x,y \in \Lambda} A_{xy} a_x^4 a_y^4$$

acting on an extended Hilbert space, it is "solved".



- The action of quantum spin operators is not clear.
- I derived matrix elements of quantum spin operators with respect to energy eigenstates.

$$\langle \phi_{\mathfrak{I}}^{\sigma'}, \tilde{S}_x^{\mu} \phi_0^{\sigma} \rangle$$

$$= C^{\sigma\sigma'} \left(\sum_{i \in I \setminus \mathfrak{I}} (-1)^{\ell(\mathfrak{I},i)} R_{xi}^{\sigma'} \mathrm{Pf} Z_{\mathfrak{I} \cup \{i\}}^{\sigma\sigma'} + \sum_{i \in \mathfrak{I}} (-1)^{\ell(\mathfrak{I},i)} \overline{R_{xi}^{\sigma'}} \mathrm{Pf} Z_{\mathfrak{I} \setminus \{i\}}^{\sigma\sigma'} \right)$$

#19

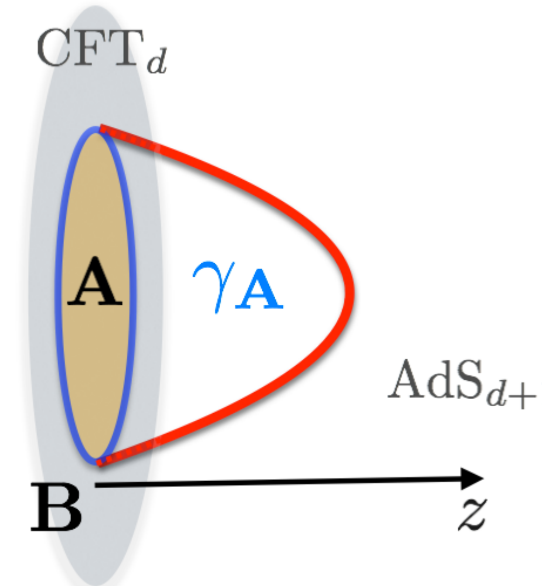
Time-evolution of Holographic Entanglement Entropy and Metric perturbations

Jung Hun Lee (Kyung Hee Univ.)
Based on (arXiv:1512.02816) with Nakwoo Kim (Kyung Hee Univ.)

- **Entanglement Entropy has holographic descriptions of quantum gravity by AdS/CFT correspondence.** [Ryu,Takayanagi 06]

von Neumann formula : $\mathbf{S_A} = -\mathrm{Tr}_{\mathbf{A}}[\rho_{\mathbf{A}} \log \rho_{\mathbf{A}}]$

Holographic EE : $\mathbf{S_A} = \dfrac{\mathbf{Area}(\gamma_{\mathbf{A}})}{\mathbf{4G_N}^{(\mathbf{d+1})}}$



- ***The motivation is to see how small excitations in the gravity side manifest itself in HEE.***

- **We consider the small cap-like surfaces in the bulk and compute HEE perturbatively in deformed AdS vacuum. (ex. AdS-BHs, AdS-scalar systems)**

Time-evolution of Holographic Entanglement Entropy and Metric perturbations

Jung Hun Lee (Kyung Hee Univ.)
Based on (arXiv:1512.02816) with Nakwoo Kim (Kyung Hee Univ.)

- **We found that the metric perturbation around the AdS vacuum does not effect the divergent terms and the change is in the finite part.**

- **We have computed the entanglement temperature by using the methods of holographic renormalisation.** [Bhattacpatya,Nozaki,Takayanagi,Ugajin 13] [Fefferman,Graham 85][Myers 99]

- **We have checked that the entanglement temperature is proportional to the inverse size of the system and has the same value for the systems considered in our paper.**

Thank you for listening!

#20

Quantum Entanglement in Topological Phases on a Torus

Zhu-Xi Luo[1], Yu-Ting Hu[1], Yong-Shi Wu[1−3]

ArXiv: 1603.01777

1. Department of Physics and Astronomy, University of Utah, Salt Lake City, Utah, 84112, U.S.A.
2. Key State Laboratory of Surface Physics, Department of Physics and Center for Field Theory and Particle Physics, Fudan University, China
3. Collaborative Innovation Center of Advanced Microstructures, Fudan University, China

Quantum Entanglement in Topological Phases on a Torus

1. Phases with intrinsic topological order have (among other features),

    1) ground state degeneracy on nontrivial manifolds;

    2) bulk-edge correspondence;

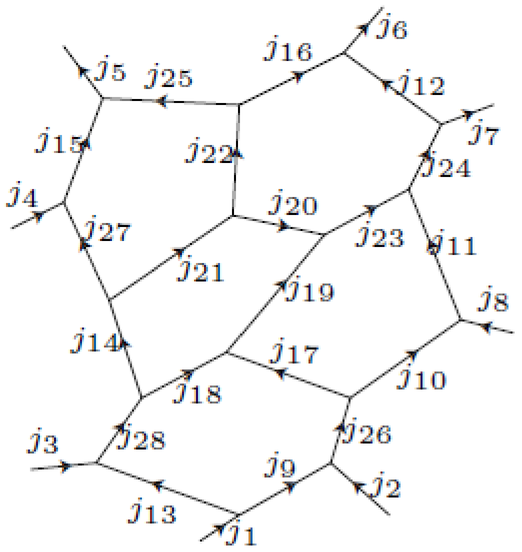
    3) long-range entanglement.

2. What does entanglement for such phases look like on nontrivial manifolds?

   How do these degenerate ground states enter?

   What other information is involved?

3. These questions have been partially studied before[1] using Chern-Simons theory. We focus on a general set of non-chiral theories: string-net model[2].



[1] Dong, Shiying, et al. *Journal of High Energy Physics* 2008.05 (2008): 016.

[2] Levin, Michael A., and Xiao-Gang Wen. *Physical Review B* 71.4 (2005): 045110.

4. By partitioning a torus into two cylinders, we derive

$$\overline{\rho}_A = \sum_{\mathcal{J}} |c_{\mathcal{J}}|^2 \left\{ \sum_{j\in I} \frac{d_j}{d_{\mathcal{J}}} \boxed{M_{\mathcal{J}j}} \left[\frac{D}{d_j} P_j \left(\alpha^{\otimes L_1}\right) \times \frac{D}{d_j} P_j \left(\alpha^{\otimes L_2}\right) \right] \right\}.$$

$$S = aL - \gamma, \quad \gamma = -\sum_k \frac{d_k^2}{D} \log \frac{d_k^2}{D} + 2\log D - \sum_{\mathcal{J}} |c_{\mathcal{J}}|^2 \log d_{\mathcal{J}} + \sum_{\mathcal{J}} |c_{\mathcal{J}}|^2 \tilde{S_{\mathcal{J}}} - \tilde{S}'$$

5. A decomposition matrix M enters the expression which describes how bulk topological charges of the ground states decompose into boundary degrees of freedom.

$$\boxed{\mathcal{J} \to \bigoplus_j M_{\mathcal{J}j} j.}$$

6. We generalize the Minimally Entangled States[3] to Minimally Entangled Sectors.

7. Examples from abelian & non-abelian finite groups and modular tensor category are discussed.

[3] Zhang, Yi, et al. *Physical Review B* 85.23 (2012): 235151.

#21

Spectral Weight in Holographic Superfluids

Victoria Martin

Stanford University

arXiv:xxxx.xxxx Gouteraux, VM

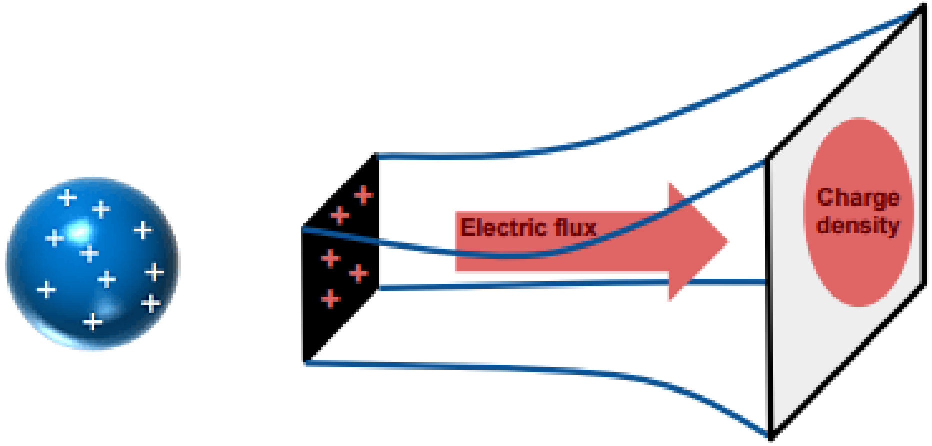
See also: arXiv:1210.1590 Anantua, Hartnoll, VM, Ramirez

YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Quantum Matter, Spacetime and Information

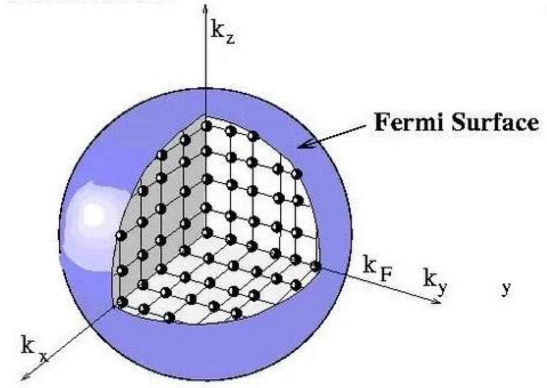
June 15, 2016

Charge behind horizon

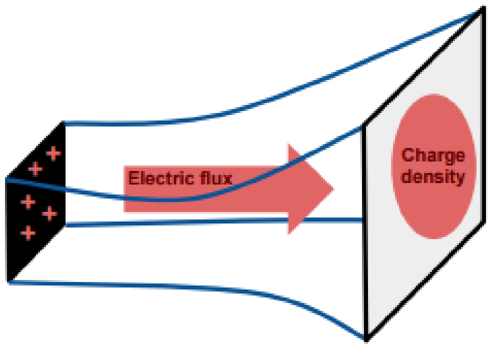


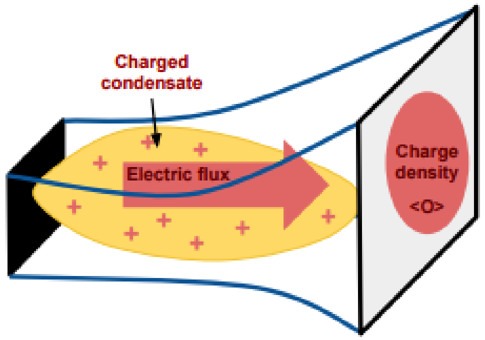
$$\boxed{G^R_{J_\perp J\perp}(\omega,k) \sim \frac{\delta A_{(1)}}{\delta A_{(0)}}}$$

Low energy spectral weight at nonzero momentum



$$\boxed{\sigma_\perp(k) = \lim_{\omega\to 0} \frac{\mathrm{Im}\, G^R_{J_\perp J_\perp}(\omega,k)}{\omega}}$$


Electric flux
Charge
density


Charged
condensate
Electric flux
Charge
density
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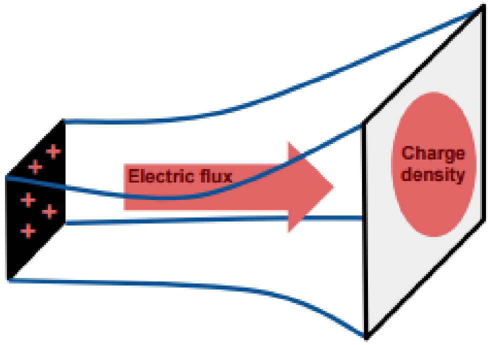
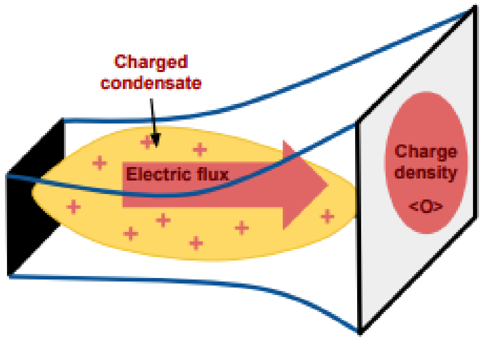
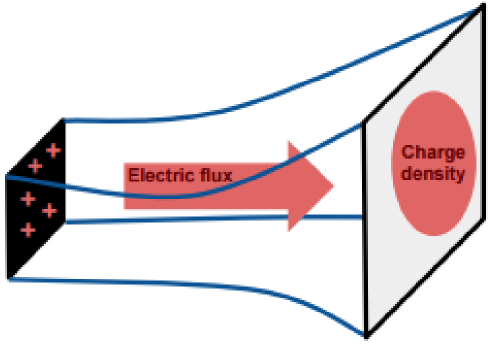
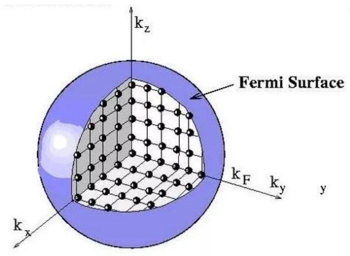
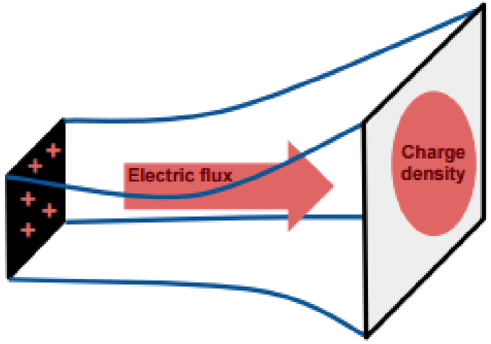


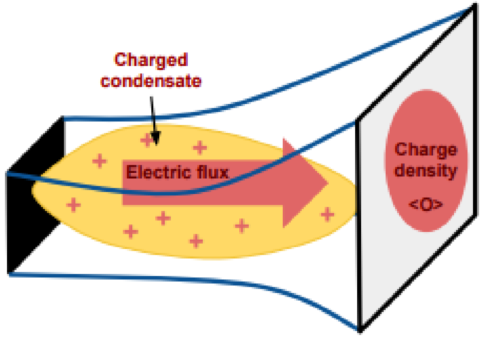


$$\sigma \neq 0 \qquad k < k_\star$$



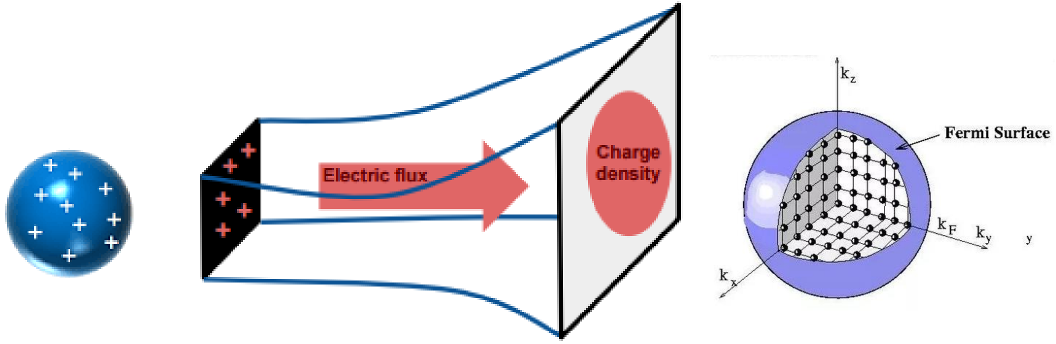


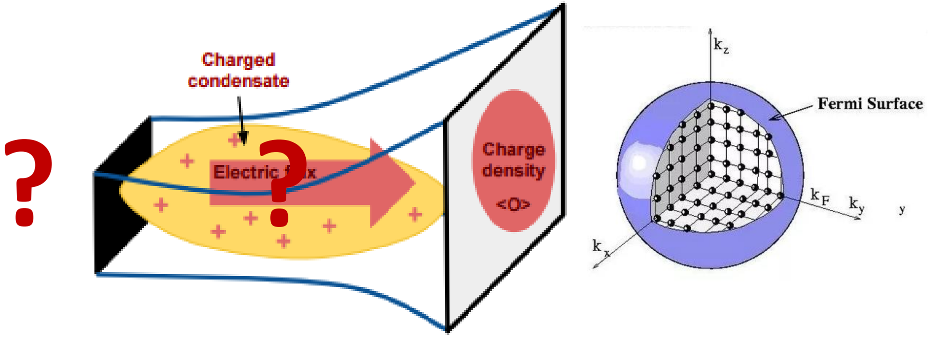


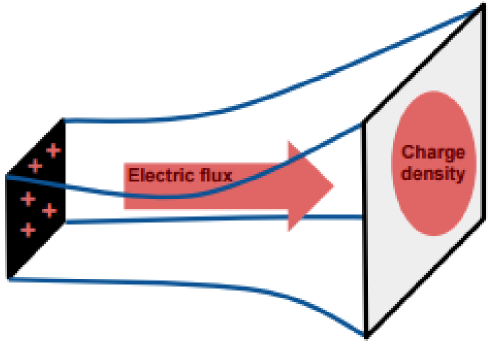


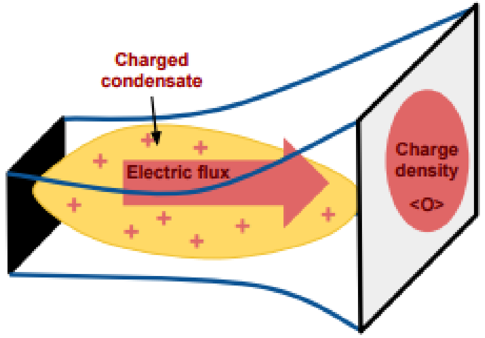
$\sigma \neq 0 \qquad k < k_\star$

$\sigma \neq 0 \qquad k < \tilde{k}$



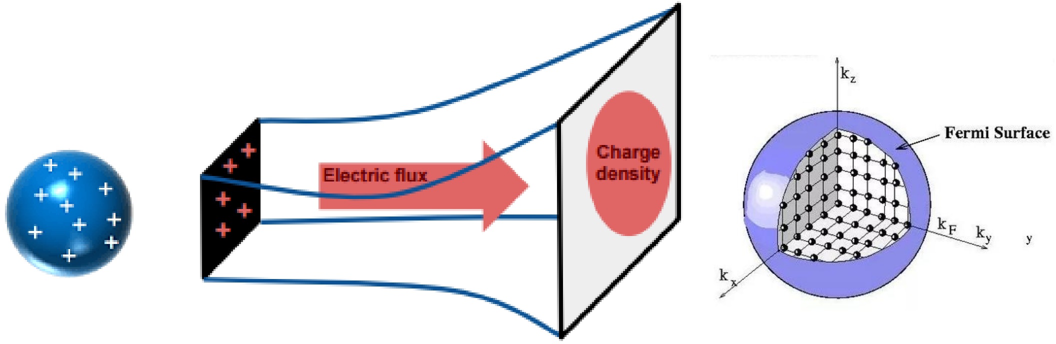


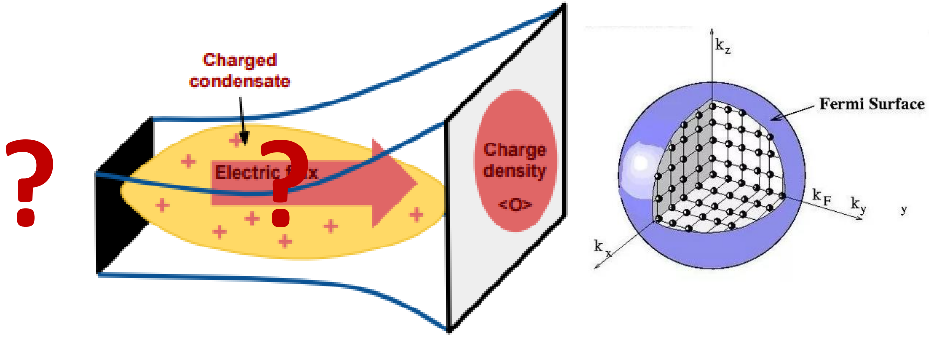




$\sigma \neq 0 \qquad k < k_\star$

$\sigma \neq 0 \qquad k < \tilde{k}$



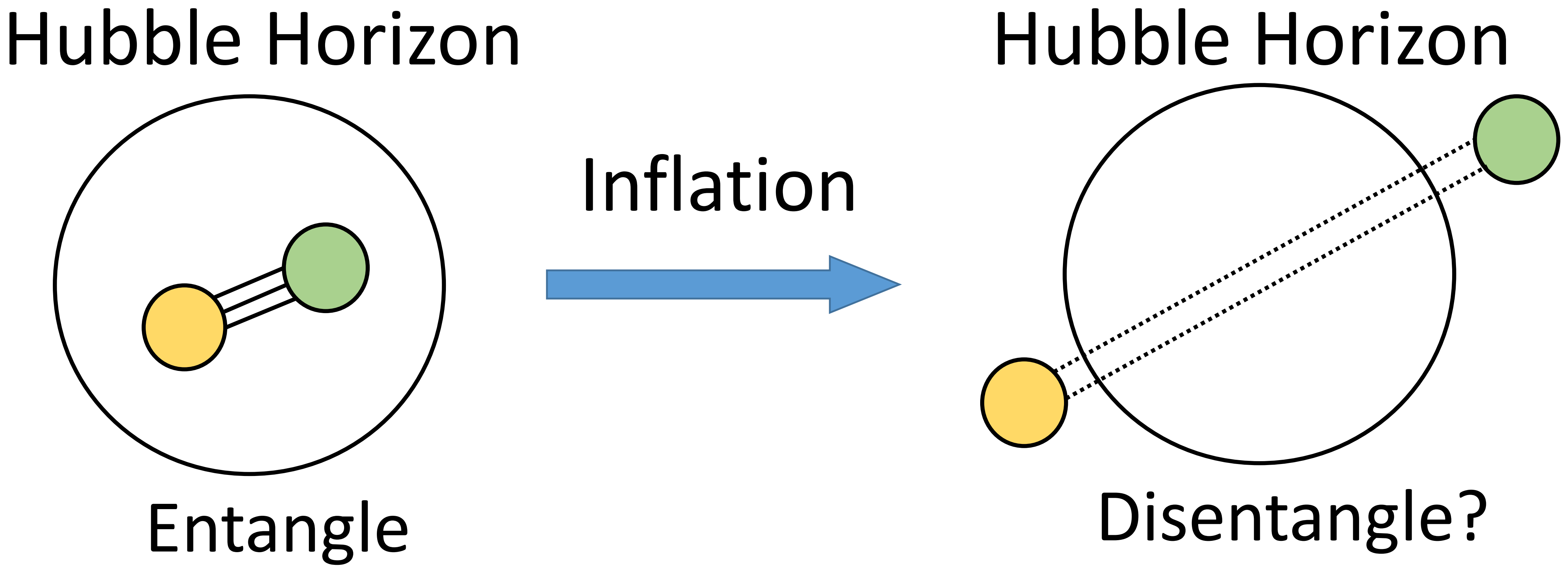


1) How should we interpret low energy spectral weight that exists independently of charge?
2) What other degrees of freedom could this weight represent?
3) To what extent do bulk charge distribution properties represent those of the boundary charge?

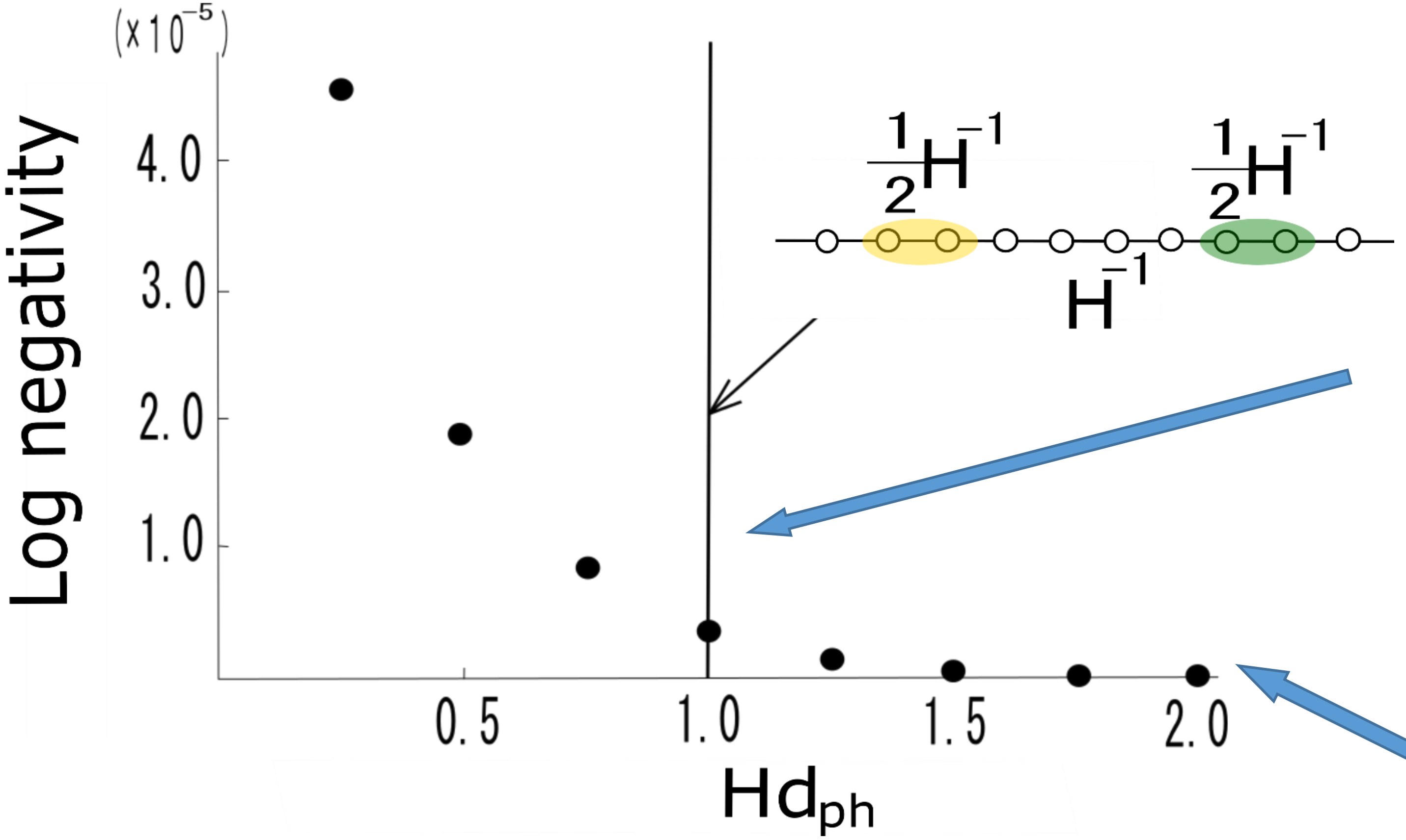
#22

Quantum Entanglement in the de Sitter Spacetime

Akira Matsumura
Yasusada Nambu (Nagoya univ.)



We investigated the entanglement in the de Sitter space.



The entanglement does not disappear .

In this scale, the entanglement is lost.

Discussion :

What a relation between the entanglement and the de Sitter spacetime structure ?

#23

Holographic Entanglement Entropy (HEE) and Field Redefinition Invariance (FRI)

M. R. Mohammadi Mozaffar

arXiv: 1603.05713

in collaboration with A. Mollabashi, M.M. Sheikh-Jabbari, M.H. Vahidinia
IPM (School of Physics)

June 2016

Field Redefinition Invariance

- Physical observables must be invariant under the field reparametrization

  (change of basis in the Hilbert space)

Example: Path Integral in QFT

$$Z = \int D\Phi(x)\; e^{-I[\Phi(x)]} = \int D\tilde{\Phi}(x)\; e^{-\tilde{I}[\tilde{\Phi}(x)]}$$

$$\Phi(x) \to \tilde{\Phi}(x) = \tilde{\Phi}[\Phi(x)] \qquad \text{non-zero Jacobian}$$

- A one-to-one correspondence between physical observables

Question

Can we find HEE functional for higher derivative gravity theories using FRI?

HEE and FRI

- Our Strategy

$$
\begin{tikzcd}
\int \sqrt{g} R + \ldots \arrow[rr, "\text{Ryu-Takayanagi}"] & & S_{EE} = \frac{min(A)}{4G} \arrow[d, "\mathcal{G}^{-1}(g)"] \\
\int \sqrt{g} f(R_{\mu\nu}) + \ldots \arrow[u, "\mathcal{G}(g)"] \arrow[rr, "\text{FPS, Dong \& ...}"'] \arrow[rr, bend left, dashed, red, "\text{Field Redef.}"] & & S_{EE}
\end{tikzcd}
$$

Achievements

- FRI extracts the new HEE functionals from the RT functional, so
  1. It gives both the HEE functional and the corresponding hypersurface
  2. It has simple generalization to time dependent cases
  3. Different entanglement inequalities satisfied

#24

Field Space Entanglement: Scalar Fields

Ali Mollabashi

School of Physics

Institute for Research in Fundamental Sciences (IPM), Theran

Based on JHEP 03 (2016) 015 (arXiv: 1509.03829),

in collaboration with M.R. Mohammadi-Mozaffar

Field Space Entanglement

- Consider a local QFT with N number of fields

$$\mathcal{L} = \mathcal{L}_1\left[\phi_1(x)\right] + \mathcal{L}_2\left[\phi_2(x)\right] + \cdots + \mathcal{L}_N\left[\phi_N(x)\right] + \mathcal{L}_{\text{int.}}\left[\phi_i(x)\right]$$

Field Space Entanglement

- Consider a local QFT with N number of fields

$$\mathcal{L} = \mathcal{L}_1\left[\phi_1(x)\right] + \mathcal{L}_2\left[\phi_2(x)\right] + \cdots + \mathcal{L}_N\left[\phi_N(x)\right] + \mathcal{L}_{\text{int.}}\left[\phi_i(x)\right]$$

- Hilbert space decomposition

$$\mathcal{H}_{\text{tot.}} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \cdots \otimes \mathcal{H}_N$$

Field Space Entanglement

- Consider a local QFT with N number of fields

$$\mathcal{L} = \mathcal{L}_1\left[\phi_1(x)\right] + \mathcal{L}_2\left[\phi_2(x)\right] + \cdots + \mathcal{L}_N\left[\phi_N(x)\right] + \mathcal{L}_{\text{int.}}\left[\phi_i(x)\right]$$

- Hilbert space decomposition

$$\mathcal{H}_{\text{tot.}} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \cdots \otimes \mathcal{H}_N$$

- Reduced density matrix

$$\rho(m, N) = \mathrm{Tr}_{\mathcal{H}_{(N-m)}}\left[\rho_{\text{tot.}}\right]$$

Field Space Entanglement

- Consider a local QFT with N number of fields

$$\mathcal{L} = \mathcal{L}_1\left[\phi_1(x)\right] + \mathcal{L}_2\left[\phi_2(x)\right] + \cdots + \mathcal{L}_N\left[\phi_N(x)\right] + \mathcal{L}_{\text{int.}}\left[\phi_i(x)\right]$$

- Hilbert space decomposition

$$\mathcal{H}_{\text{tot.}} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \cdots \otimes \mathcal{H}_N$$

- Reduced density matrix

$$\rho(m,N) = \mathrm{Tr}_{\mathcal{H}_{(N-m)}}\left[\rho_{\text{tot.}}\right]$$

- Entanglement and Renyi entropies

$$S_{\text{ent.}} = -\mathrm{Tr}\left[\rho(m,N)\log\rho(m,N)\right] \quad , \quad S^{(n)} = \frac{1}{1-n}\log\mathrm{Tr}\left[\rho^n(m,N)\right]$$

Field Space Entanglement

- Consider a local QFT with N number of fields

$$\mathcal{L} = \mathcal{L}_1\left[\phi_1(x)\right] + \mathcal{L}_2\left[\phi_2(x)\right] + \cdots + \mathcal{L}_N\left[\phi_N(x)\right] + \mathcal{L}_{\text{int.}}\left[\phi_i(x)\right]$$

- Hilbert space decomposition

$$\mathcal{H}_{\text{tot.}} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \cdots \otimes \mathcal{H}_N$$

- Reduced density matrix

$$\rho(m, N) = \mathrm{Tr}_{\mathcal{H}_{(N-m)}}\left[\rho_{\text{tot.}}\right]$$

- Entanglement and Renyi entropies

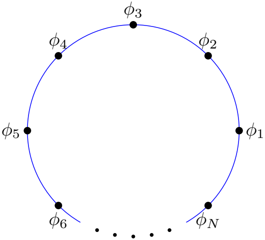
$$S_{\text{ent.}} = -\mathrm{Tr}\left[\rho(m,N)\log\rho(m,N)\right] \quad , \quad S^{(n)} = \frac{1}{1-n}\log\mathrm{Tr}\left[\rho^n(m,N)\right]$$

- Explicit models

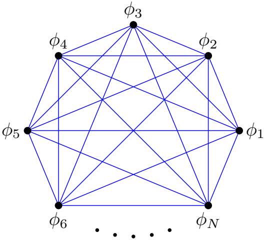
$$S = \frac{1}{2}\int d^d x\left[\sum_{i=1}^{N}\left(\partial_\mu\phi_i\right)^2 + \lambda\sum\partial_\mu\phi_i\partial^\mu\phi_j\right]$$

Our (Gaussian) Models

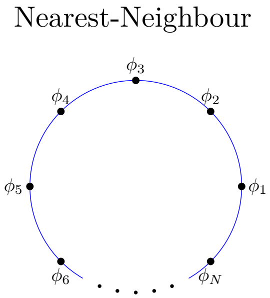
Nearest-Neighbour

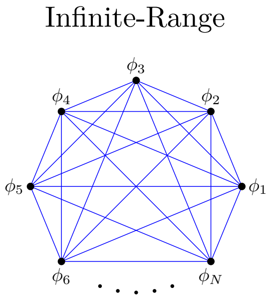


Infinite-Range



Our (Gaussian) Models





- Renyi & Araki-Lieb inequalities and SSA are satisfied
- n-partite information ≥ 0 (checked for $n \leq 5$)
- In particular $I^{(3)} \geq 0$ (existence holographic dual?)
- Infinite-Range model in $\lambda \to 0$ limit

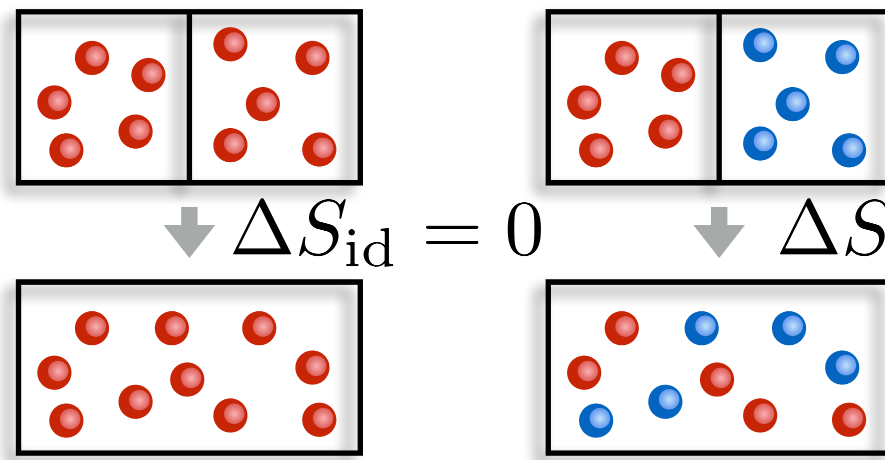
$$S^{\text{reg.}}(m) = \frac{\lambda^2 m(N-m)}{32}\left[1 - \log\frac{\lambda^2 m(N-m)}{32}\right] + \mathcal{O}\left(\lambda^3\right)$$

#25

The Gibbs paradox revisited from the fluctuation theorem with absolute irreversibility

[1]University of Tokyo, [2]RIKEN CEMS
Yûto Murashita[1], Masahito Ueda[1,2]

The Gibbs paradox from gas mixing



$\Delta S_{\mathrm{id}} = 0$ $\Delta S_{\mathrm{dif}} = 2Nk_{\mathrm{B}} \ln 2$

The Gibbs paradox has three faces

Gibbs (1875) GP-I

$\boxed{\text{GP-II}}$

GP-III Ehrenfest&Trkal (1921)

Thermodynamics $S \longleftrightarrow S^{\mathrm{stat}}$ **(Classical) statistical mechanics**

Gibbs (1902)

The three faces are resolved in the thermodynamic limit

van Kampen (1984)
Jaynes(1992)

However, GP-II is partially open in small systems!

The Gibbs paradox revisited from the fluctuation theorem with absolute irreversibility

[1]University of Tokyo, [2]RIKEN CEMS Yûto Murashita[1], Masahito Ueda[1,2]

Theme of GP-II

$$S(T,V,N) = S^{\mathrm{stat}}(T,V,N) + k_{\mathrm{B}} f(N)$$

Removing the ambiguity $f(N)$

*The quantum resolution is irrelevant in this context

In the thermodynamic limit

Extensivity

$$S(T,qV,qN) = qS(T,V,N)$$

$$\Leftrightarrow f(N) = -N\ln N + N\mathrm{const.} \simeq -\ln N!\ (N\to\infty)$$

In a small thermodynamic system

Fluctuation theorem with absolute irreversibility

$$\langle e^{-\beta(W-\Delta F)}\rangle = 1-\lambda$$

$$\Leftrightarrow f(N) = -\ln N! + N\mathrm{const.}$$

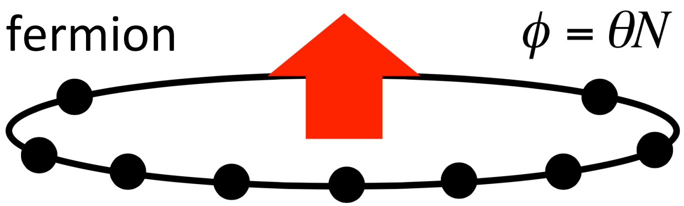
#26

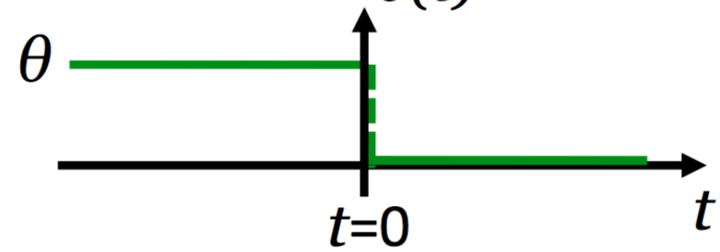
Flux quench in a system of interacting spinless fermions in one dimension

Yuya Nakagawa (ISSP, Univ. of Tokyo)

Nakagawa, Misguich, Oshikawa, arXiv:1601.06167

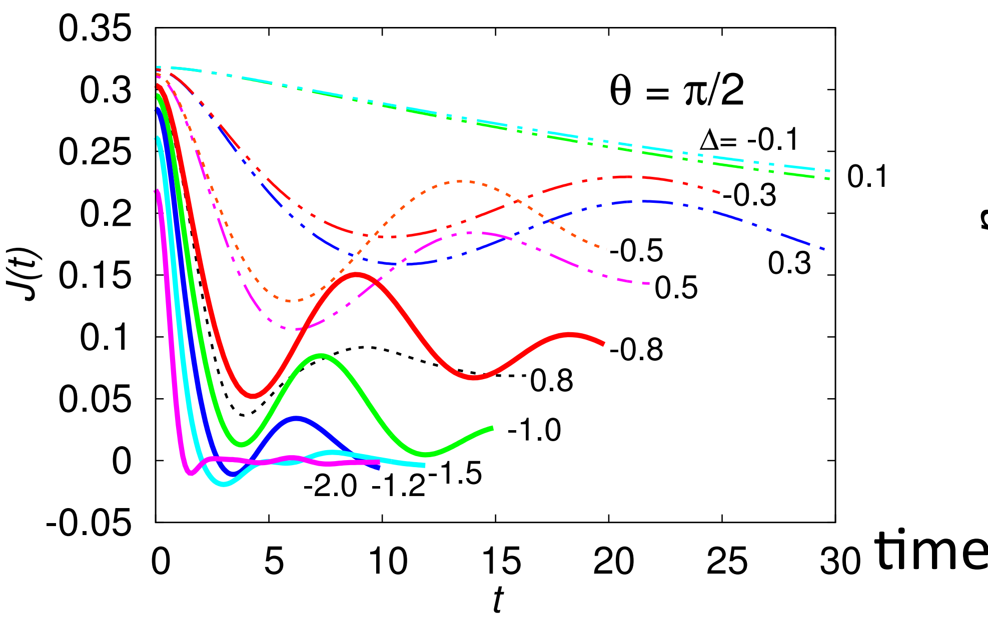
- Quantum quench of the flux piercing an interacting spinless fermion chain
- Numerical calculation of the dynamics of particle current after the quench



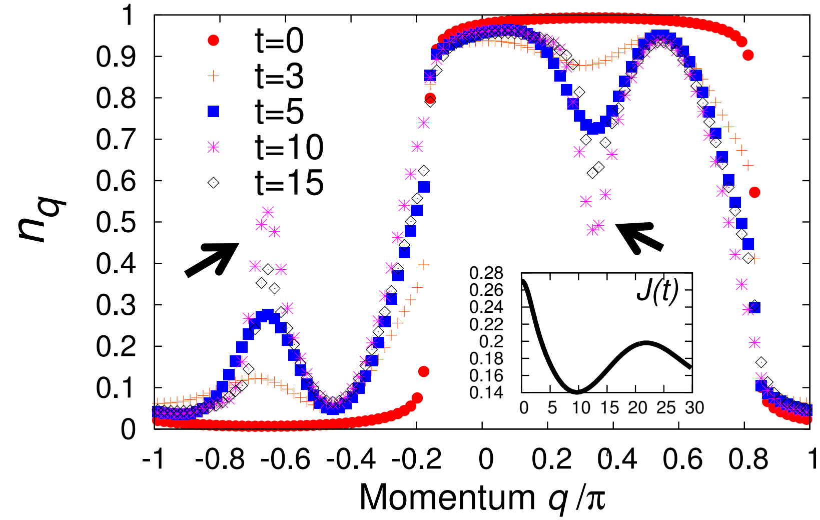


$$H(t) = -\frac{1}{2}\sum_i \left(e^{-i\theta(t)} c_i^\dagger c_{i+1} + e^{i\theta(t)} c_{i+1}^\dagger c_i \right) - \Delta \sum_i n_i n_{i+1}$$

Dynamics of the current



Dynamics of momentum distribution

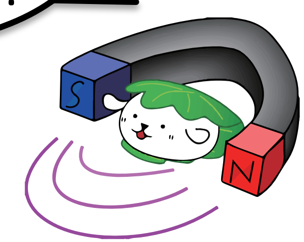


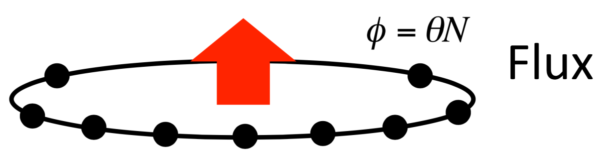
Oscillations are due to selective Umklapp scattering!!

Other results:

- strong nonlinearity of J(t=∞) in relation with the Drude weight
- thermalizations in integrable model

please see .gif animation!





$$H(t) = -\frac{1}{2}\sum_i \left(e^{-i\theta(t)} c_i^\dagger c_{i+1} + e^{i\theta(t)} c_{i+1}^\dagger c_i\right) - \Delta \sum_i n_i n_{i+1}$$

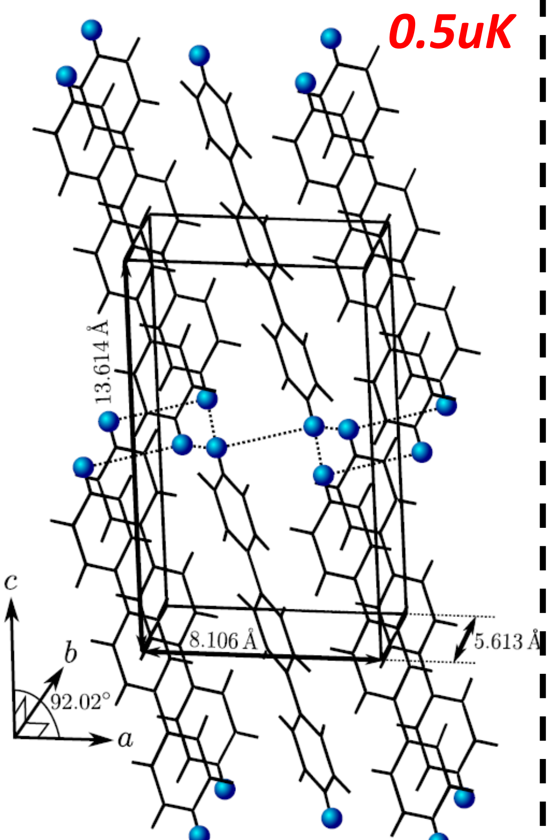
arXiv:1601.06167

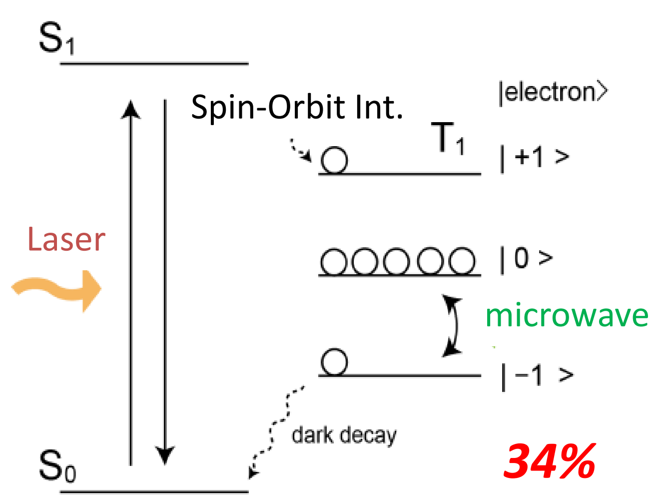
#27

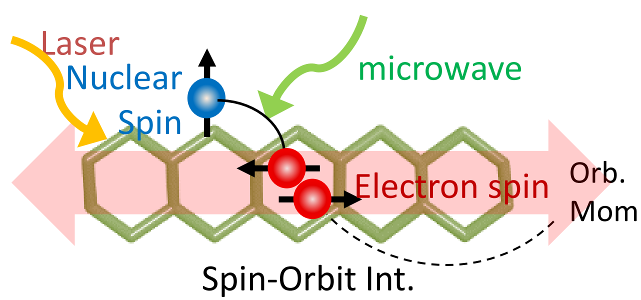
Quantum Annealing with Hyperpolarized Nuclear Spins

M. Negoro @ Eng. Sci., Osaka Univ.

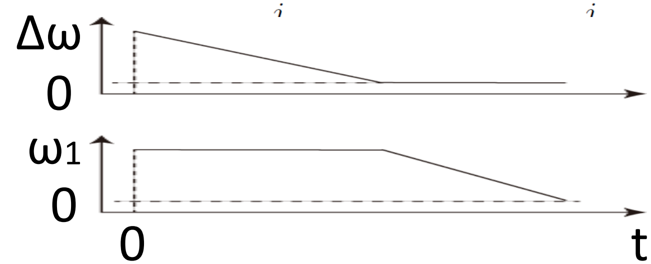
Proposal for nuclear ferro or anti-ferro @ room temperature

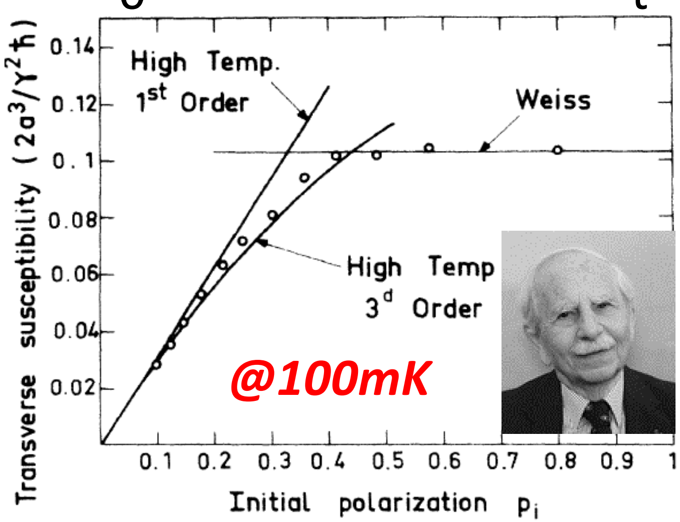






$$\mathcal{H}_{\rm rot} = \Delta\omega \sum_j I_j^z + \mathcal{H}'_d + \omega_1 \sum_j I_j^x$$





#28

Entanglement dynamics of Majorana fermions

Takumi Ohta *Yukawa Institute for Theoretical Physics, Kyoto University*

With Shu tanaka, Ippei Danshita, and Keisuke Totsuka

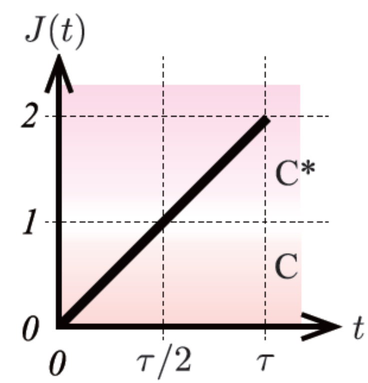
Reference: Phys. Rev. B 93, 165423 (2016)

Dynamical properties of Majorana fermions

- Sweep dynamics with OBC

  Sweep from C phase to C* phase

$$H(t) = -J^{XZX}\sum_{i=1}^{N}\sigma_i^x\sigma_{i+1}^z\sigma_{i+2}^x + J(t)\sum_{i=1}^{N}\sigma_i^y\sigma_{i+1}^z\sigma_{i+2}^y$$



$$J(t)/J^{XZX} = 2t/\tau, \quad 0 \le t \le \tau$$

τ : Sweep time

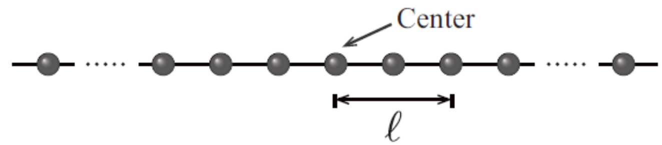
- Physical quantities

  String correlation functions (SCFs)

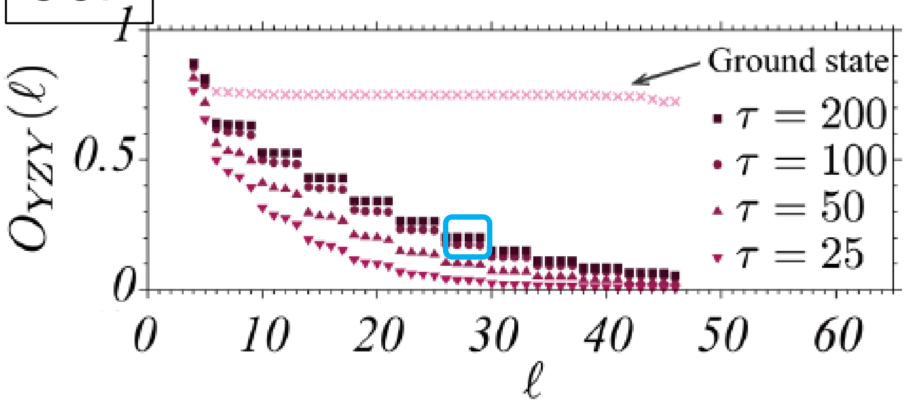
  entanglement entropy (EE), spectrum (ES)

Digest of Dynamics

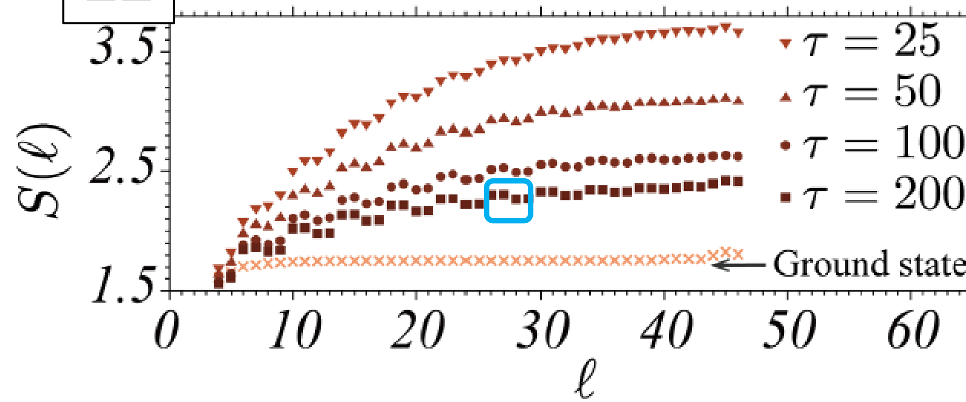
Spatially periodic structure @ $t = \tau$



SCF

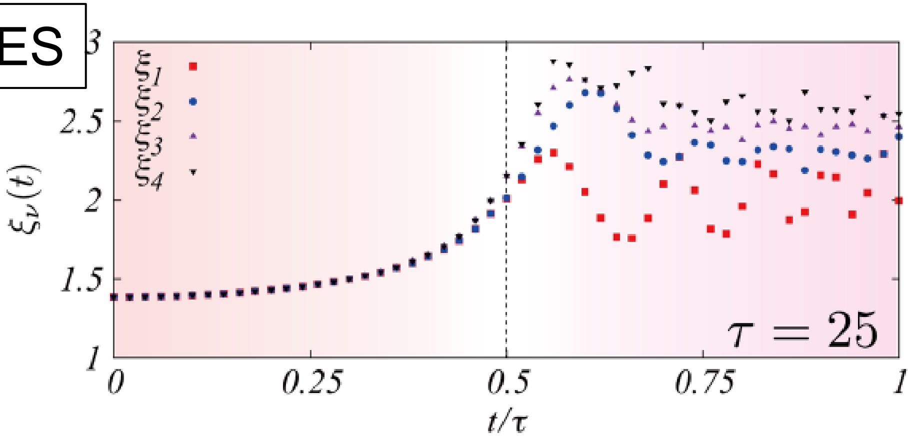


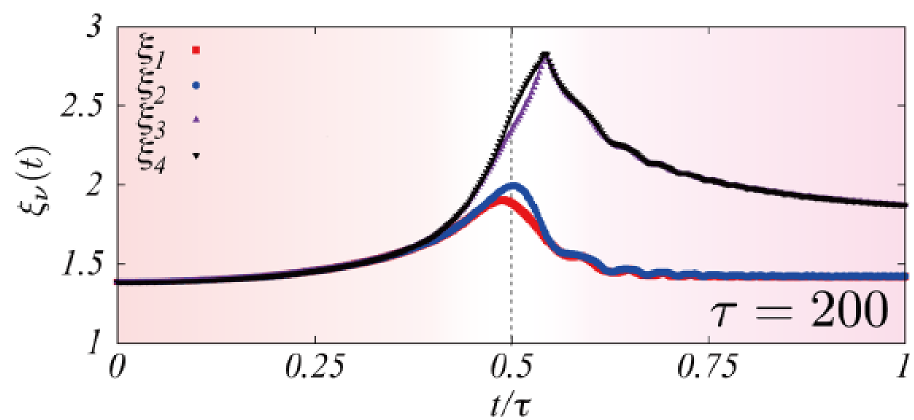
EE

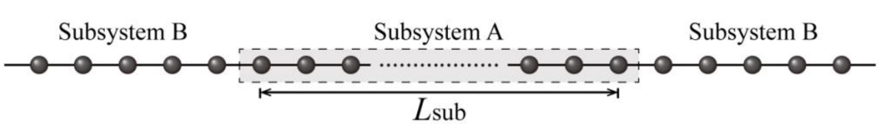


Oscillating and splitting structures in time

ES







$N = 101, \; L_{\mathrm{sub}} = 49$

#29

Universality of Black Hole Quantum Computing

Benedikt Richter

Physics of Information and Quantum Technologies Group, IT, Lisboa

IST, Universidade de Lisboa

ASC, Ludwig-Maximilians-Universität München

joint work with

Gia Dvali (LMU, MPP, NYU)

Cesar Gomez (LMU, UAM-CSIC)

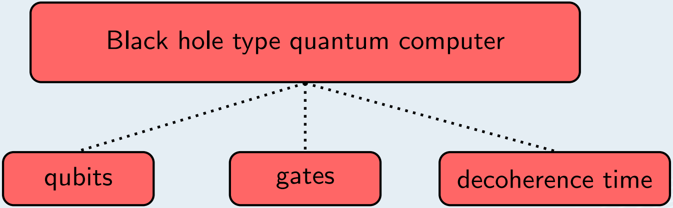
Dieter Lüst (LMU, MPP)

Yasser Omar (IT, IST)

based on arXiv: 1605.01407

Black Hole Quantum Computing

By analyzing the key properties of black holes, we derive a model-independent picture of black hole quantum computing.



Main results:

time scales for gate operations, (local) decoherence and life-time **coincide**:

$$t_{gate} \sim t_{decoh} \sim t_{life-time}$$

$\Rightarrow$ maximal circuit depth is trivial,

$\Leftrightarrow$ **Trade-off between memory and information processing capacity**

#30

"Quantum Matter, Spacetime and Information",
June, 13-17, 2016

YITP
YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Paola Ruggiero

The entanglement negativity in random spin chains

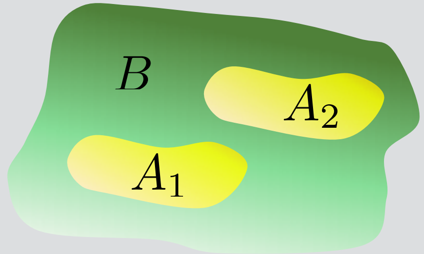
with V. Alba, P. Calabrese
arXiv:1605.00674

ma per seguir virtute e canoscenza
SISSA

ENTANGLEMENT NEGATIVITY IN MANY BODY SYSTEMS

$$\mathcal{E}_{A_1:\,A_2} = \ln Tr|\rho^{T_2}|$$

$$\langle e_i, e_j|\rho_A^{T_2}|e_k e_l\rangle = \langle e_i, e_l|\rho_A|e_k e_j\rangle$$



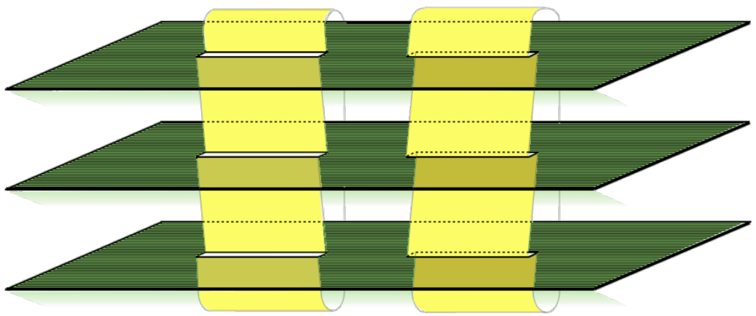
“GOOD MEASURE” OF ENTANGLEMENT: **PURE STATES**
MIXED STATES

QFT METHODS: **[CALABRESE, CARDY, TONNI, 2011]**

REPLICA APPROACH: $\mathcal{E} = \lim_{n_e \to 1} \ln Tr(\rho^{T_2})^{n_e}$

EXACT RESULTS AVAILABLE IN CFT:

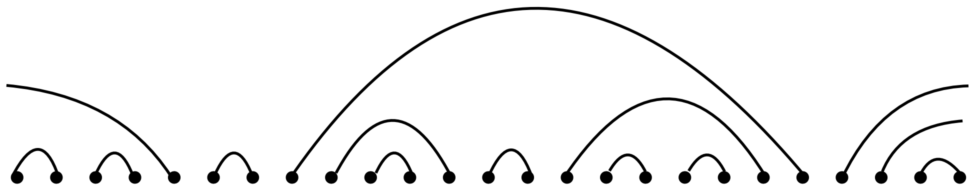
$$tr(\rho_A^{T_2})^n = \mathcal{N}\langle \mathcal{T}(u_1,0)\tilde{\mathcal{T}}(v_1,0)\tilde{\mathcal{T}}(u_2,0)\mathcal{T}(v_2,0)\rangle$$

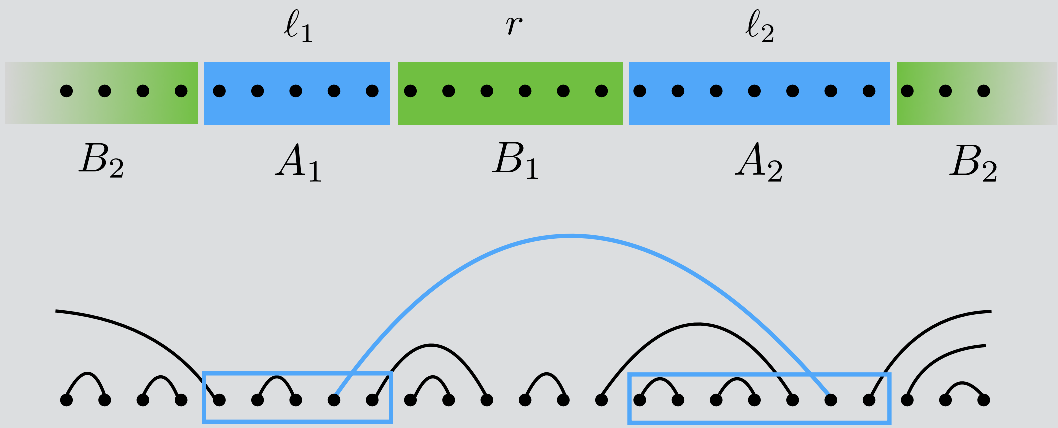


NEGATIVITY IN RANDOM SPIN CHAINS

STRONG DISORDER RG

RANDOM SINGLET PHASE
(XX, HEISENBERG, ISING)





SINGLE REALIZATION OF THE DISORDER:

$$\mathcal{E}_{A_1:A_2} \sim n_{A_1:A_2} \log 2$$

AVERAGE OVER DISORDER (SDRG)

ADJACENT INTERVALS:

$$\langle \mathcal{E}_{A_1:A_2} \rangle \sim \frac{\log 2}{6} \log \left(\frac{\ell_1 \ell_2}{\ell_1 + \ell_2} \right)$$

DISJOINT INTERVALS:

$$\langle \mathcal{E}_{A_1:A_2} \rangle = -\frac{\log 2}{6} \log \left(1 - \frac{\ell_1 \ell_2}{(\ell_1 + r)(\ell_2 + r)} \right)$$

#31

Entanglement Entropy of Scattering Particles

Shigenori Seki

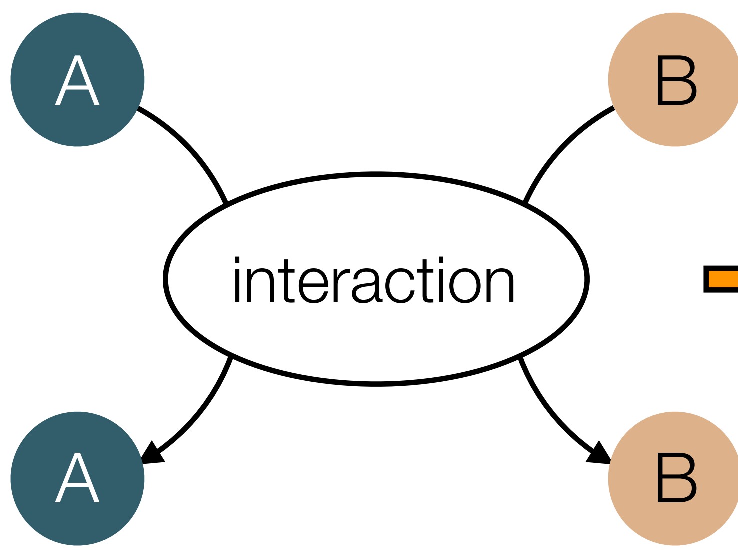
This poster presentation is based on the work:

R. Peschanski (IPhT, CEA-Saclay) and SS,
"Entanglement entropy of scattering particles", Phys. Lett. B758 (2016) 89.

QUESTION

Let us consider a scattering process of two particles.

unentangled
initial state



$|\mathrm{ini}\rangle = |\vec{k}\,\rangle_A \otimes | -\vec{k}\,\rangle_B$ (center of mass)

S-matrix $\mathcal{S}$

final state
(two particles)

$|\mathrm{fin}\rangle = Q\mathcal{S}|\mathrm{ini}\rangle$

(Q : projection operator onto the
Hilbert space of two-particle states)

What is the entanglement entropy between the particles in the two-particle final state?

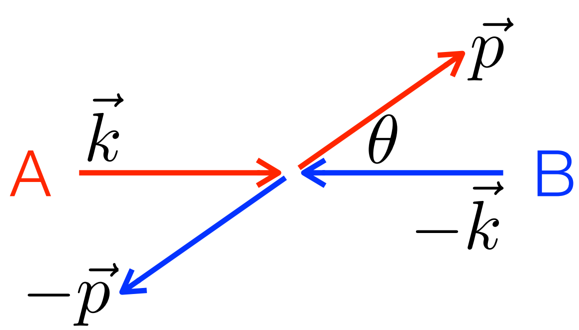
OUR ANSWER

There are elastic and inelastic channels: $A + B \to A + B$ "elastic"

$A + B \to X$ "inelastic" (multi-particle)

By using partial wave expansions, we calculate the entanglement entropy;

$$S_{\mathrm{EE}} = -\ln \frac{\left|\sum_\ell (2\ell+1) s_\ell\right|^2}{\sum_{\ell,\ell'} (2\ell+1)(2\ell'+1)|s_\ell|^2}$$



$$\frac{\pi k}{E_{A\vec{k}} + E_{B\vec{k}}} \langle\langle \vec{p}|\mathbf{s}|\vec{k}\rangle\rangle = \sum_\ell (2\ell+1) s_\ell P_\ell(\cos\theta)$$

$$s_\ell = 1 + 2i\tau_\ell\,, \quad \mathrm{Im}\tau_\ell = |\tau_\ell|^2 + \frac{1}{2} f_\ell$$ (unitarity)

By introducing the physical Hilbert space, we obtain the formula that describes the entanglement entropy in terms of physical observables;

$$S_{\mathrm{EE}} = -\ln K\,, \quad K \sim 1 - \frac{\sigma_{\mathrm{el}} - \frac{1}{R^2} \frac{d\sigma_{\mathrm{el}}}{dt}\Big|_{t=0}}{4\pi R^2 - \sigma_{\mathrm{inel}}}$$

σ_{el} : integrated elastic cross section $\qquad \dfrac{d\sigma_{\mathrm{el}}}{dt}$: differential elastic cross section

σ_{inel} : integrated inelastic cross section $\qquad R$: maximal impact parameter

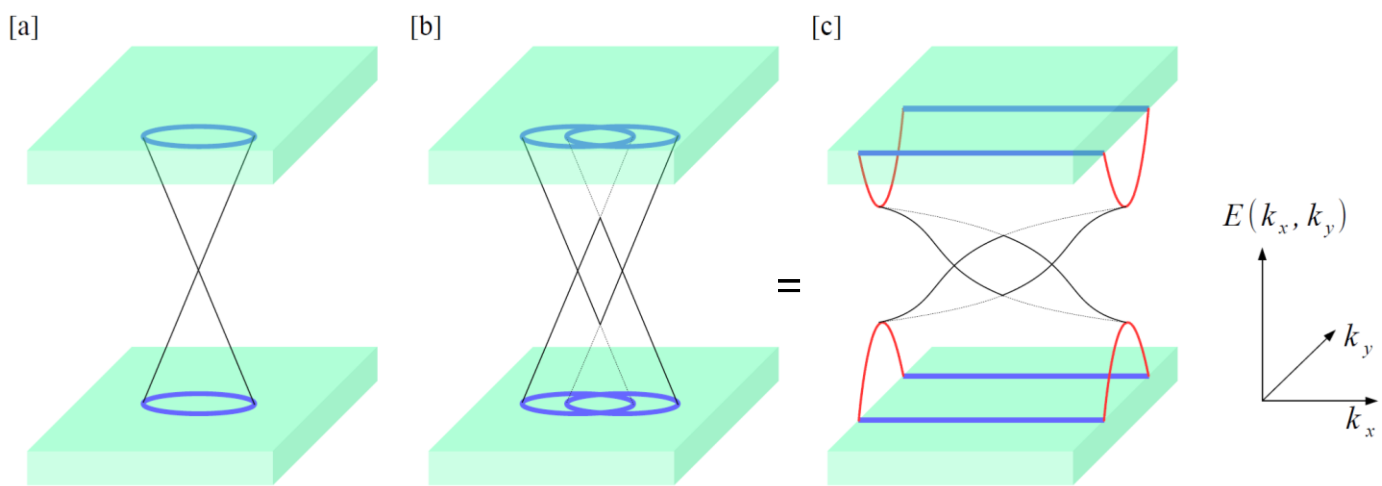
#32

Z4 topological crystalline insulators and superconductors

Ken Shiozaki, University of Illinois at Urbana Champaign

KS, M. Sato, K. Gomi, arXiv:1511.01463

- Topological insulators + nonsymmorphic space group
- Periodic table from K-theory
- Glide + Time-reversal symmetry → Z4 phase



Z4= 1 phase

Z4=2 phase

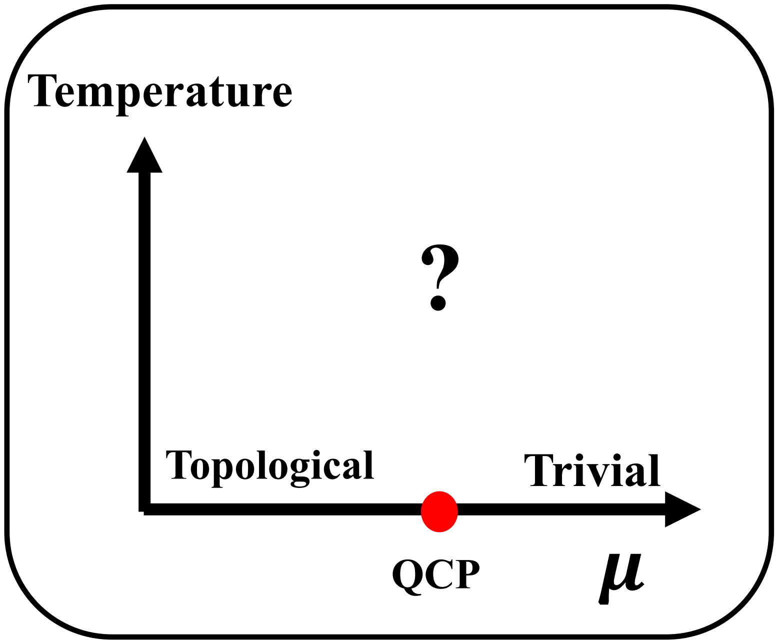
#33

Sudden Death and Birth of Topological Entanglement in 1D Fermions at Finite Temperature

YeJe Park, Seung-Sup Lee and Heung-Sun Sim*
KAIST, Korea

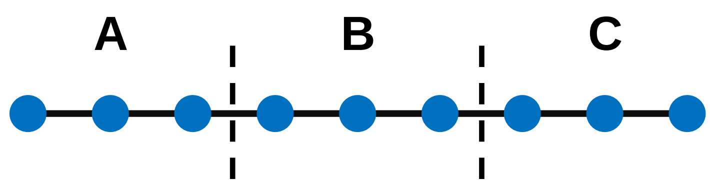
Question

At T = 0,
a topological phase defined in terms of GS.
At **T > 0,**
how do we characterize a 1D topological SC ?

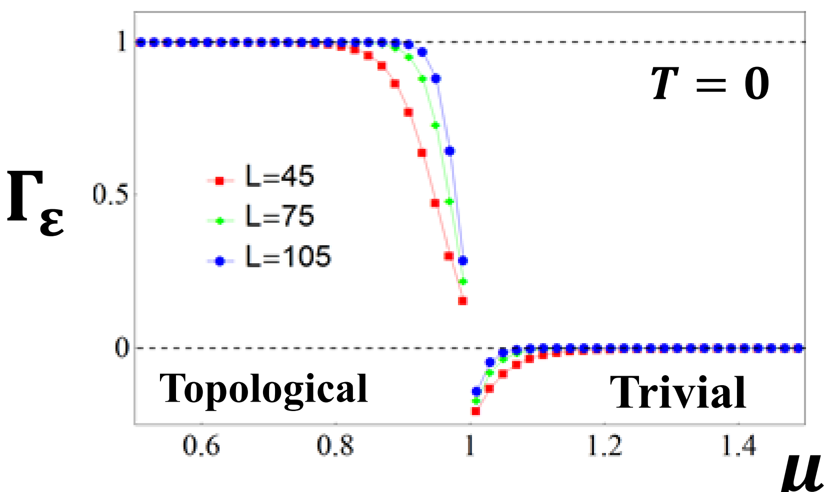


Our solution

Use mixed-state entanglement measure $\varepsilon_{X|Y}(\rho)$
to introduce a topological quantity $\boldsymbol{\Gamma_\varepsilon(\rho)}$.



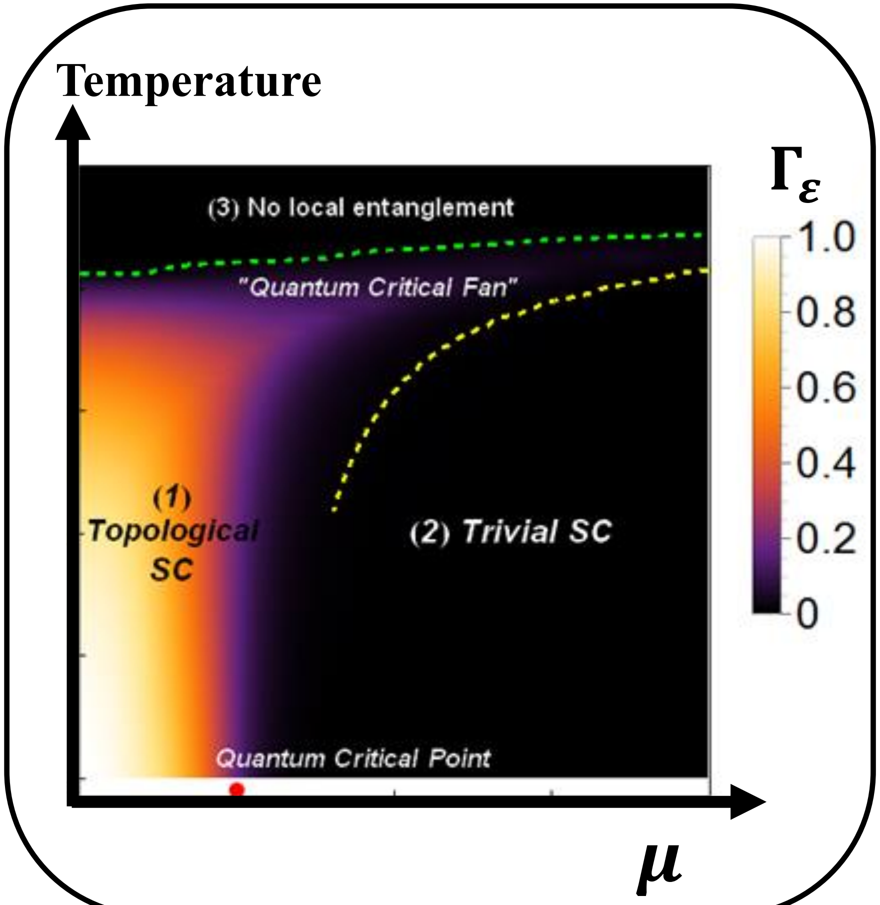
$$\boldsymbol{\Gamma_\varepsilon(\rho)} = \varepsilon_{B|AC}(\rho) - \varepsilon_{A|BC}(\rho) - \varepsilon_{C|AB}(\rho)$$



Sudden Death and Birth of Topological Entanglement in 1D Fermions at Finite Temperature

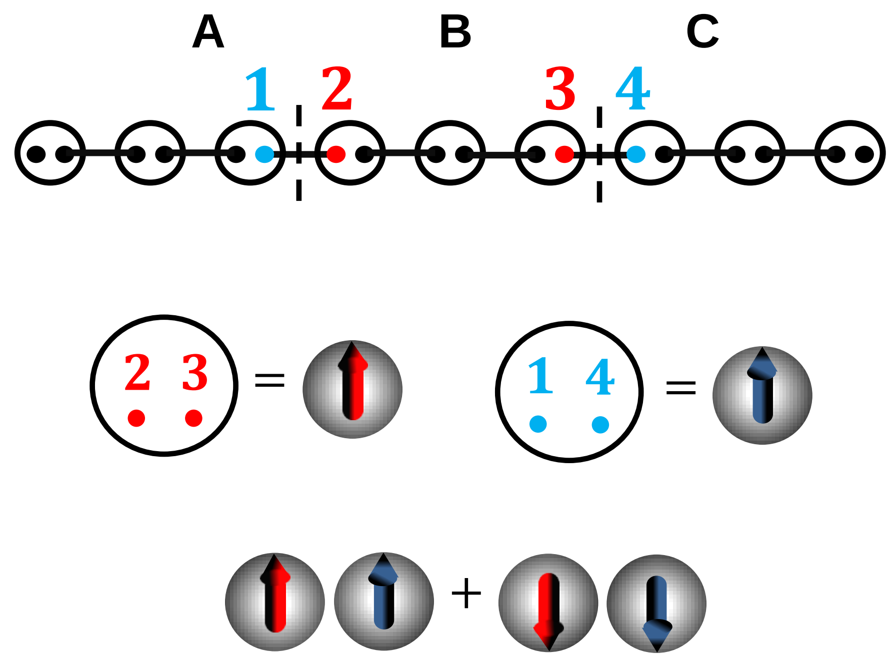
YeJe Park, Seung-Sup Lee and Heung-Sun Sim*
KAIST, Korea

Topological quantity Γ_ε at T > 0



Majorana fermions as entangled nonlocal qubits

In the topological region at T > 0, the nonlocal qubits formed by bulk Majoranas are entangled.

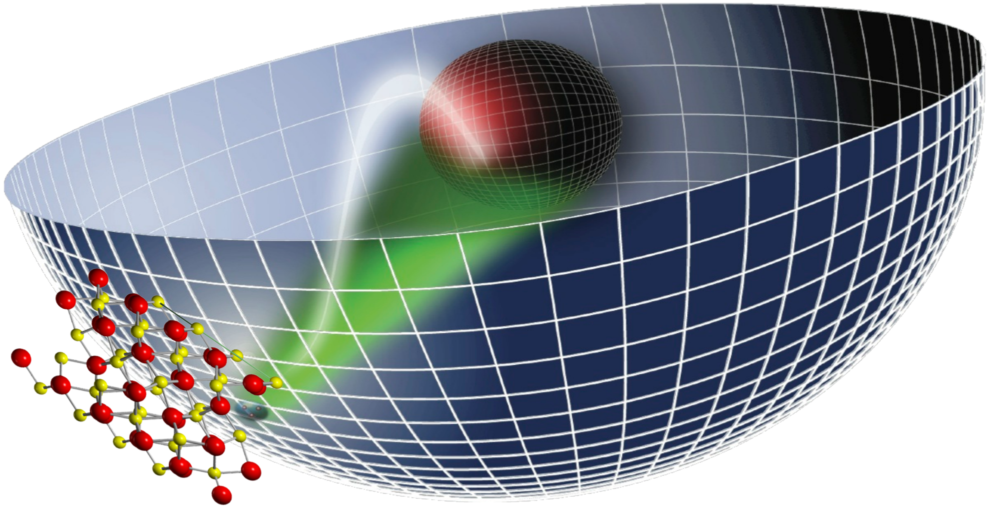


#34

A few examples for Holography vs. experiment

Sang-Jin Sin (HYU)

2016.06.15@Kyoto



Anomalous Hall coefficient Rs

$$\rho_H \equiv R_H H + R_s M_0,$$

arXiv:1512.08916 **Phys.Lett. B759 (2016) 104-109**

KY. Kim, KK.Kim, Y.Seo + sj

For Intrinsic deflection/ Side jump $\quad R_s \sim \rho_{xx}^2.$

For skew scattering $\quad R_s \sim \rho_{xx}.$

$$2\kappa^2 S = \int d^4x\sqrt{-g}\left\{R + \frac{6}{L^2} - \frac{1}{4}F^2 - \sum_{I=1,2}\frac{1}{2}(\partial\chi_I)^2\right\} - \frac{1}{16}\int q_\chi(\partial\chi_I)^2 F\wedge F +$$

$$R_s = \frac{3}{r_0\mu}\frac{1}{\theta^2 + (1+\mu^2/\beta^2)^2} \qquad \rho_{xx} = \frac{1+\mu^2/\beta^2}{\theta^2 + (1+\mu^2/\beta^2)^2}$$

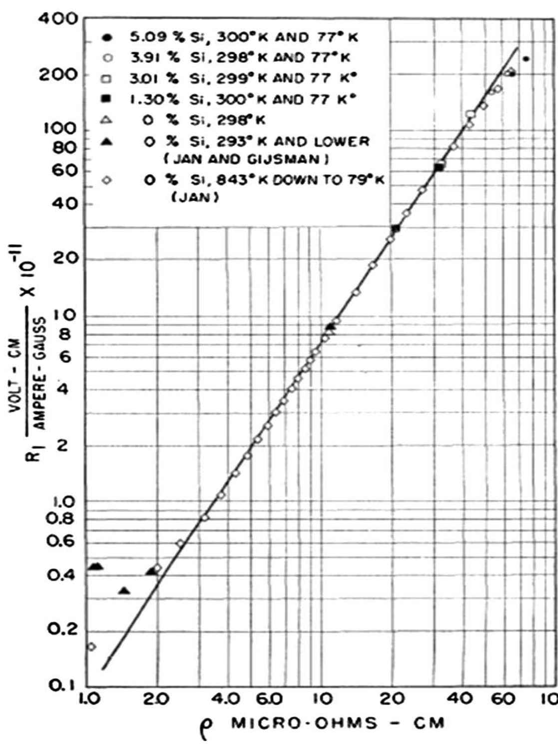
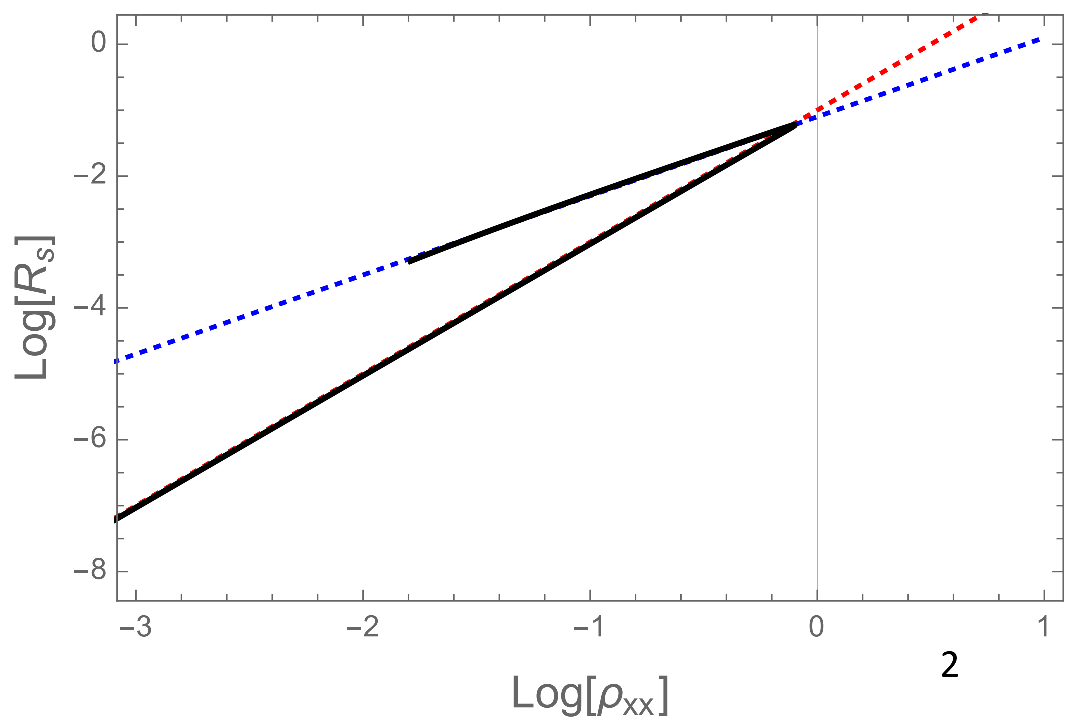


FIG. 2. Extraordinary Hall constant as a function of resistivity. The shown fit has the relation $R_s \sim \rho^{1.9}$. From Kooi, 1954.

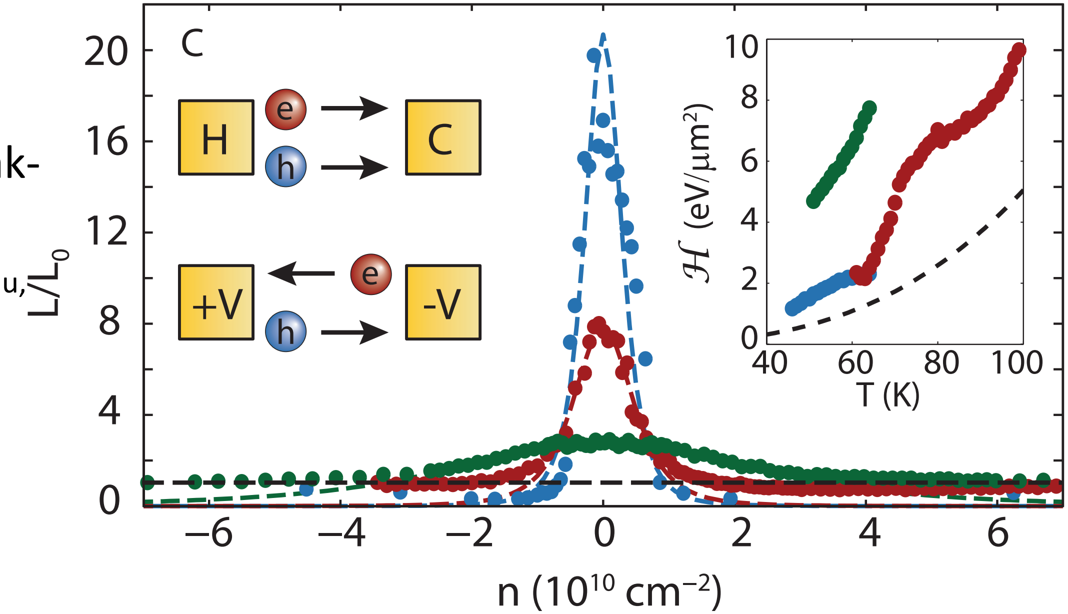


Theory vs. experiment in Dirac Fluid of graphene

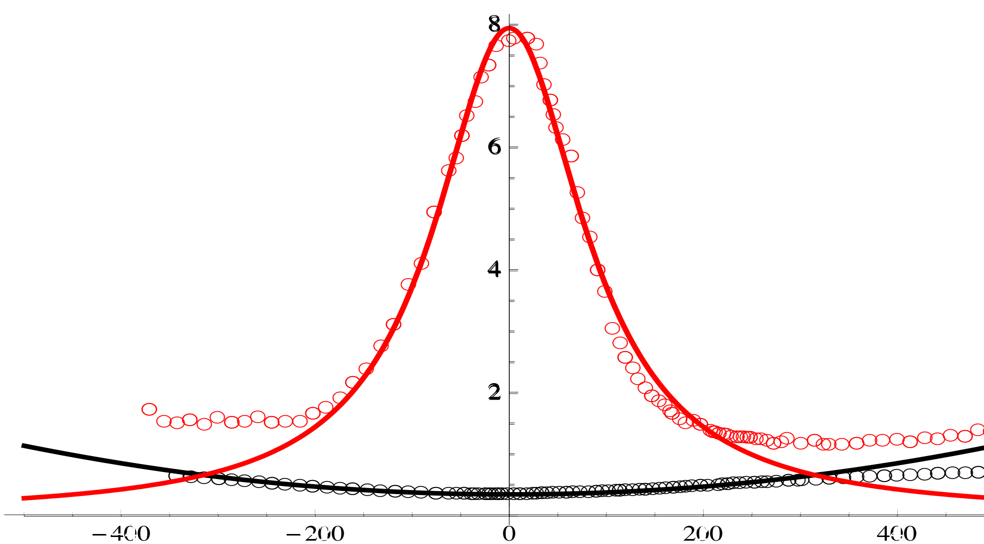
Science 11 Feb 2016

Observation of the Dirac fluid and the break-down of the Wiedemann-Franz law in graphene

Jesse Crossno, Jing . Shi, Ke Wang, Xiaomeng Liu, Achim Harzheim, Andrew Lucas, Subir Sachdev, Philip Kim,*, Takashi Taniguchi, Kenji Watanabe, Thomas A. Ohki5, Kin Chung Fong,*



Holography (HYU) to appear
U(1) x U(1)

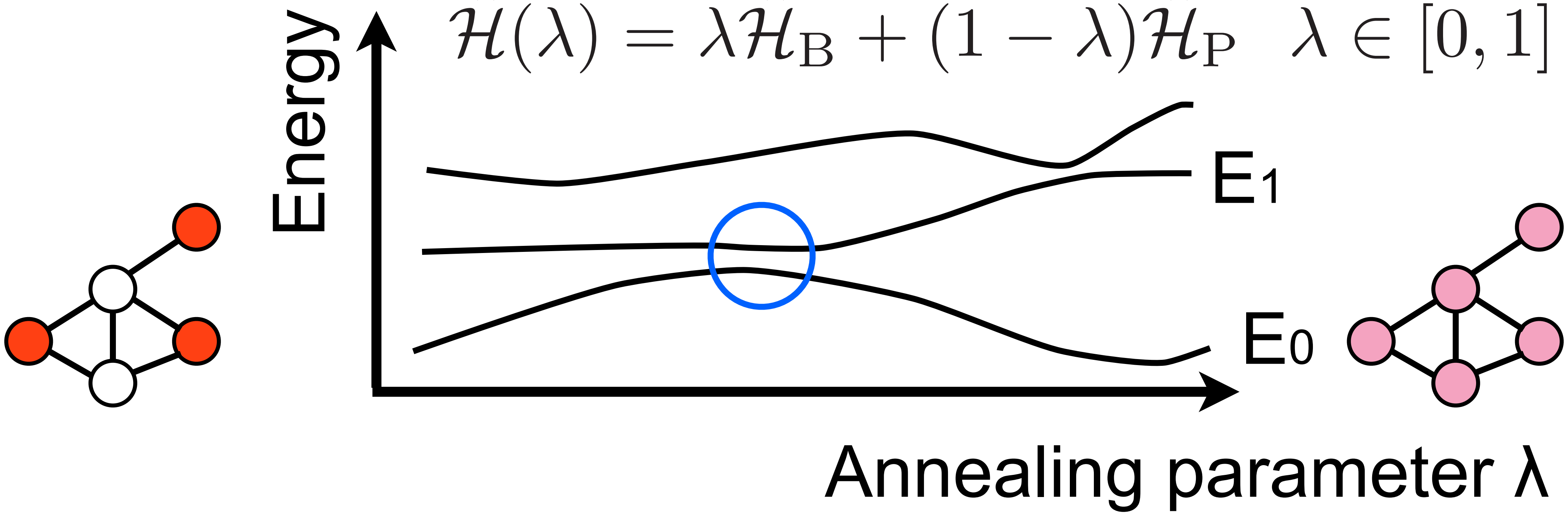


#35

Fidelity approach to Adiabatic Quantum Computation of hard problems

Jun Takahashi (Univ. of Tokyo)

$$\hat{\mathcal{H}}(\lambda) = \lambda \hat{\mathcal{H}}_{\mathrm{B}} + (1-\lambda)\hat{\mathcal{H}}_{\mathrm{P}} \quad \lambda \in [0,1]$$



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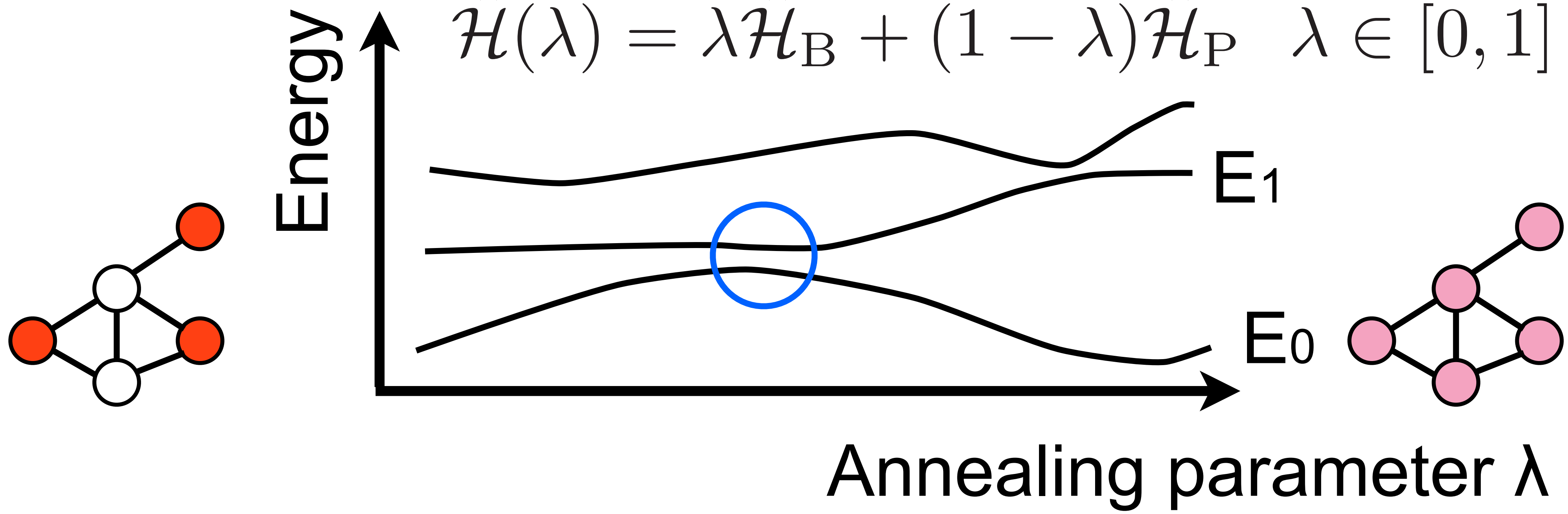

Q.

When AQC is applied to an **NP-hard** problem,
what is the ***physical mechanism***
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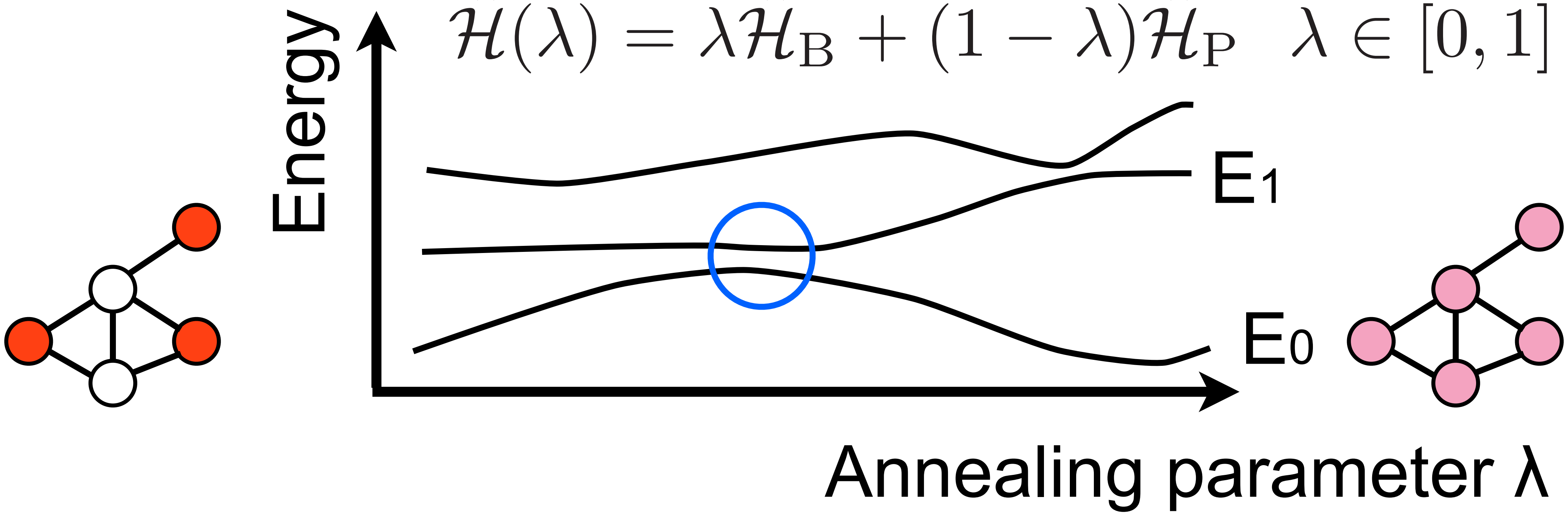

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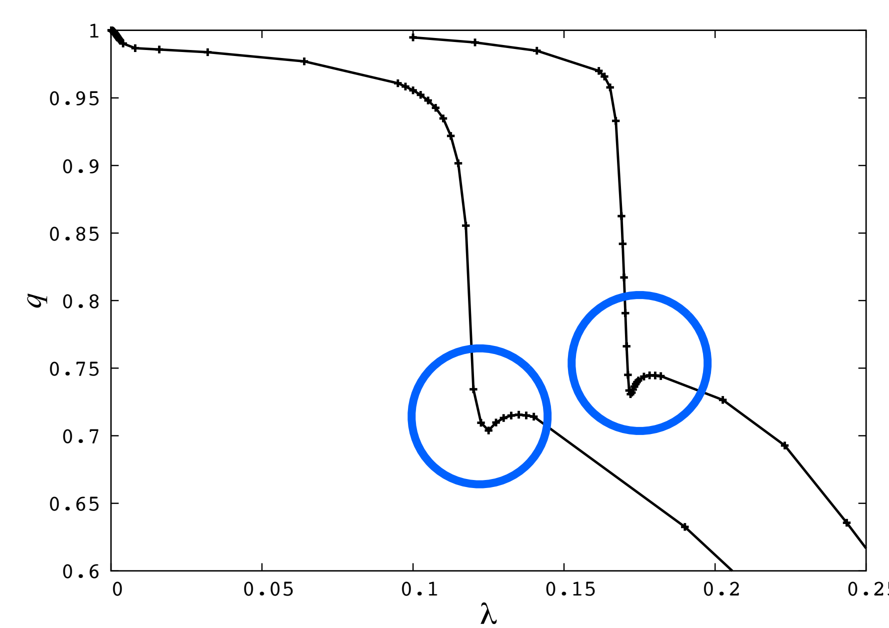
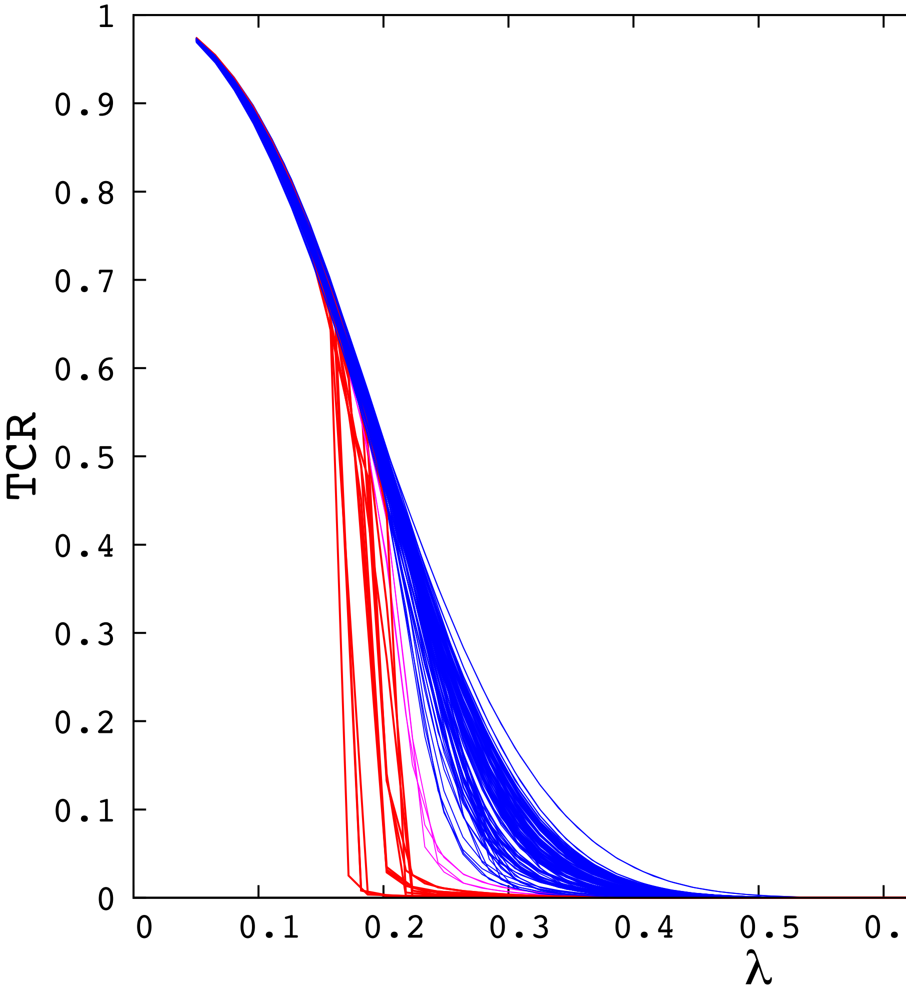
A. (so far)

1st order phase transition (-like) phenomena



Main Question

The 1st-order phase transitions are actually ***strongly sample dependent***.
Can we understand them as a whole?
(e.g. a non self-averaging behavior within a spin glass phase?)



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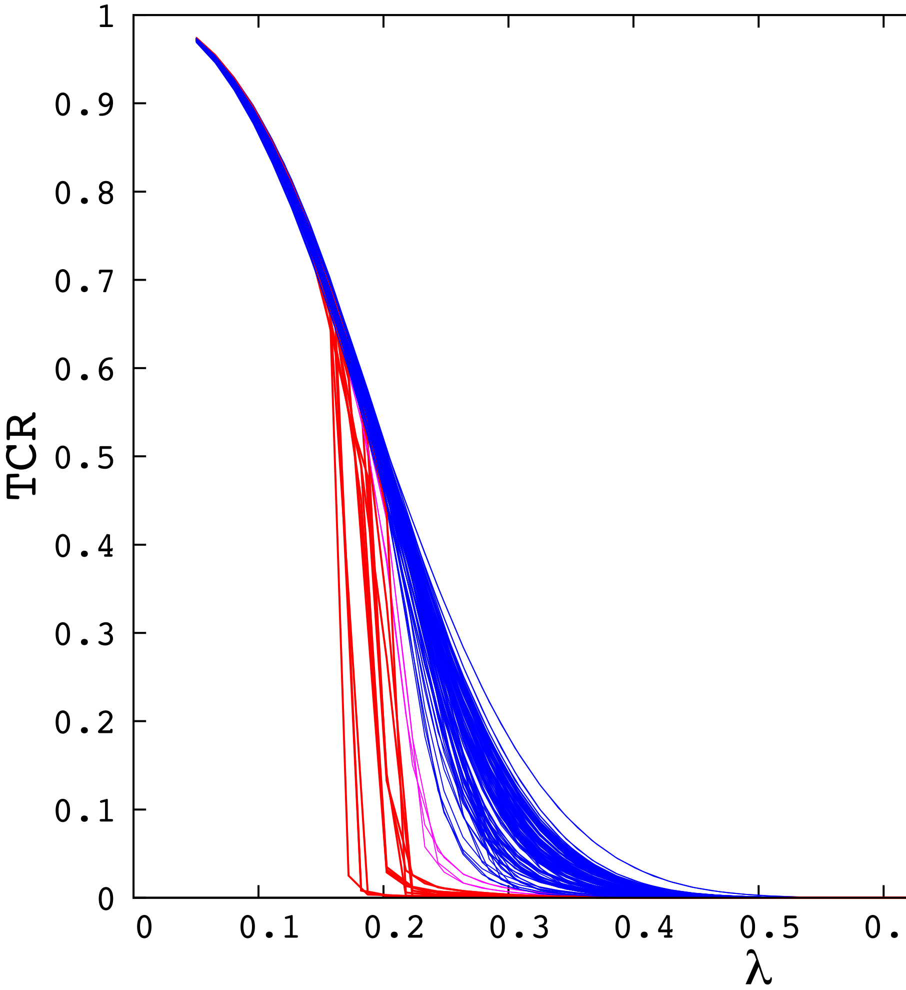

Method

fix: Maximum Independent Set as a NP-complete problem
Stochastic Series Expansion (SSE) + Replica Exchange (λ direction)

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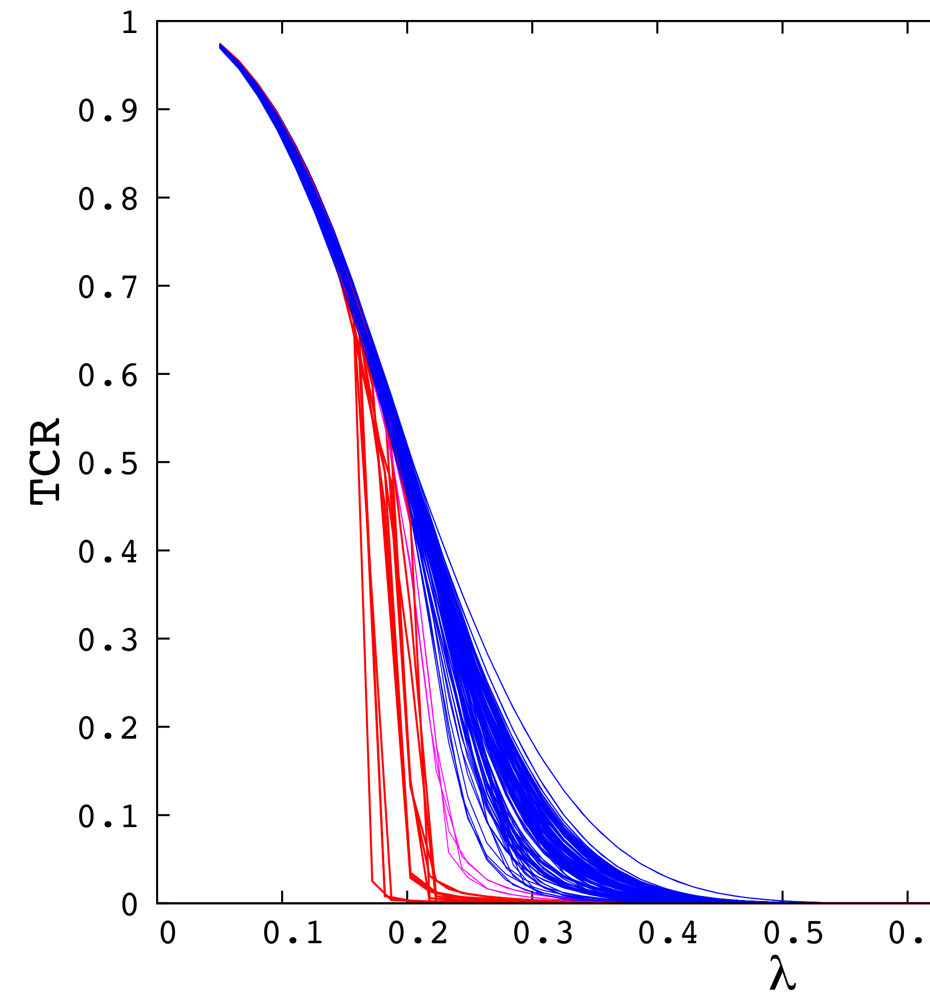

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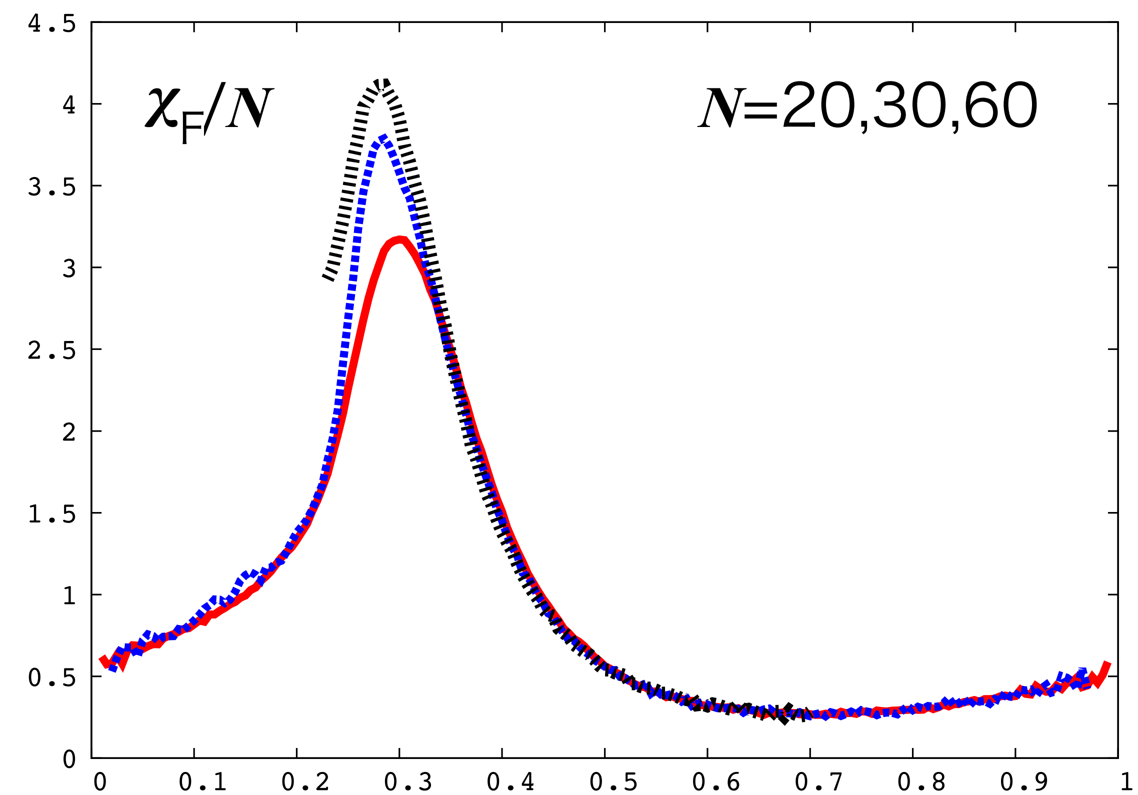
Our study suggests that fidelity susceptibility is so far the best way to see the sample-averaged phase transition



#36

Super Yang-Mills ↔ IIA/IIB-string
M-theory
(BH, black brane)

Sachdev-Ye-Kitaev model ↔ BH in AdS_2

Numerical study of real-time correlation function

Comparison with analytical results, random-matrix limit

Free disordered system

Sparse random matrix models

Dense random matrix model
GUE, GOE, GSE

Increasing disorder degrees of freedom →

#37

Fixed Point Matrix Product States and 1+1D Topological Quantum Field Theory

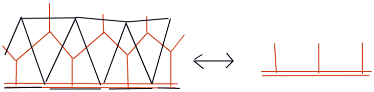
Alex Turzillo

California Institute of Technology
Based on work with Anton Kapustin and Minyoung You

June 14, 2016

Idea

- Matrix Product States (MPS) efficiently approximate ground states of 1D gapped local Hamiltonians. Each gapped phase of these Hamiltonians corresponds to a Fixed Point MPS.
- Lattice TQFT also describes gapped systems at fixed points.
- Idea: build a dictionary between these two frameworks.
  - both are classified by the same algebraic data
  - MPS and parent Hamiltonians arise from the state-sum



Generalizations

- The algebraic data that classifies these theories makes sense in other categorical contexts $\Rightarrow$ generalizations
- Idea: passing structured (*ie* not strictly topological) field theories through the dictionary returns variants of MPS.
- Equivariant TQFT $\longrightarrow$ Symmetric MPS
  - describes gapped symmetric phases: SPTs/SETs
  - twisted sectors and symmetry breaking
- Spin TQFT $\longrightarrow$ Fermionic MPS
  - describes fermionic phases, *eg* the nontrivial Majorana chain
  - related to symmetric MPS by bosonization

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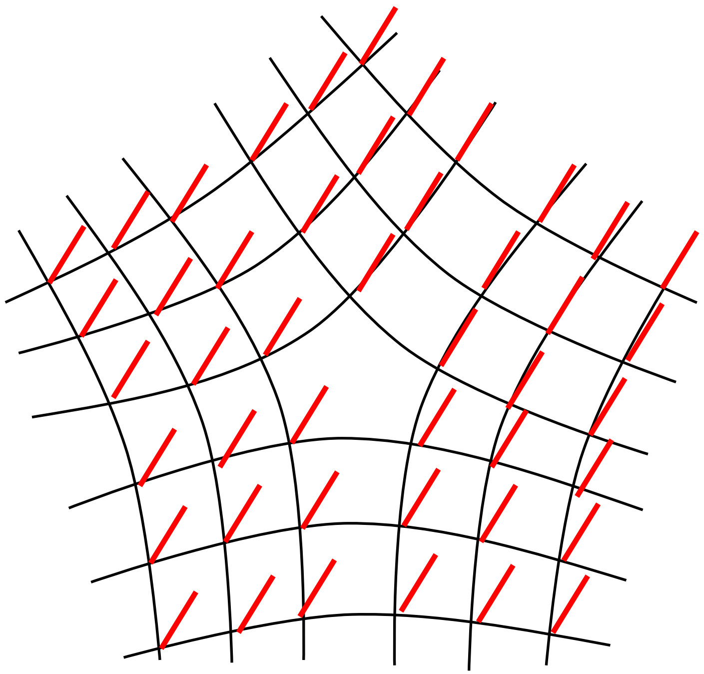
#39

Holographic duality from random tensor

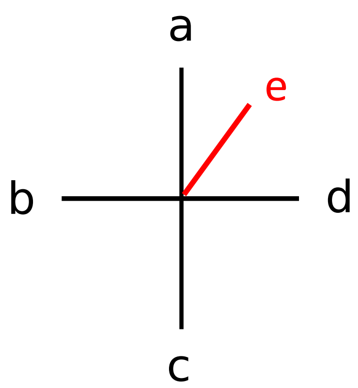
arxiv:1601.01694

Construction



$$= \sum_{a_1 \ldots a_n, b_1 \ldots b_m} M_{a_1 a_2 \ldots a_n, b_1 b_2 \ldots b_m} |a_1 a_2 \ldots a_n\rangle\langle b_1 b_2 \ldots b_m|$$

Every vertex:



$$= \sum_{abcde} T_{abcde} |abcde\rangle$$

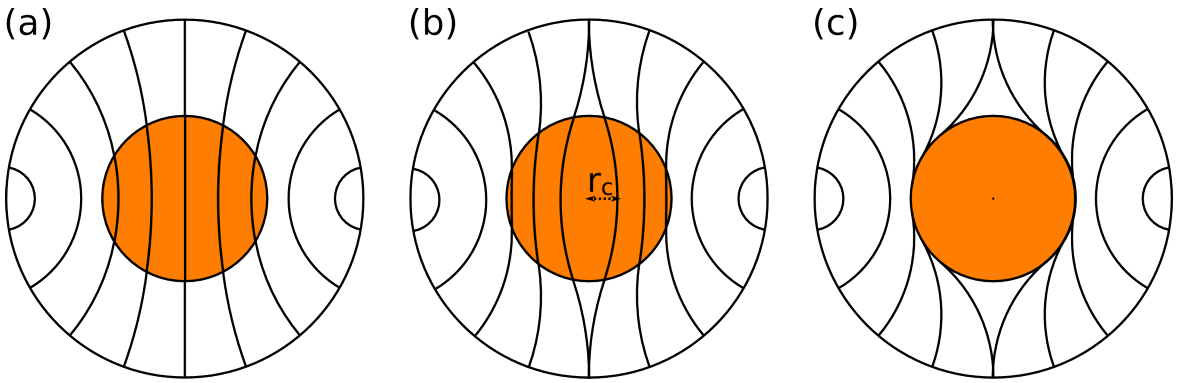
Haar random state in the product Hilbert space $\otimes_{i=1}^{5} \mathcal{H}_i$

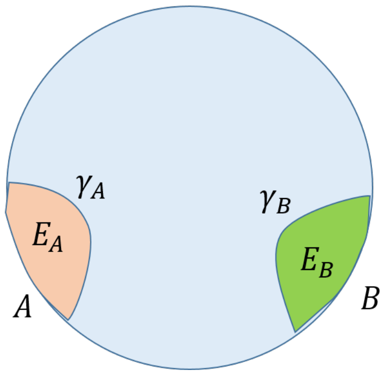
Holographic duality from random tensor

arxiv:1601.01694

Properties

- RT formula & bulk correction
  Hawking-Page transition
- Quantum error correction
- Correlation spectrum





#40

Engineering Holographic Superconductor Phase Diagrams

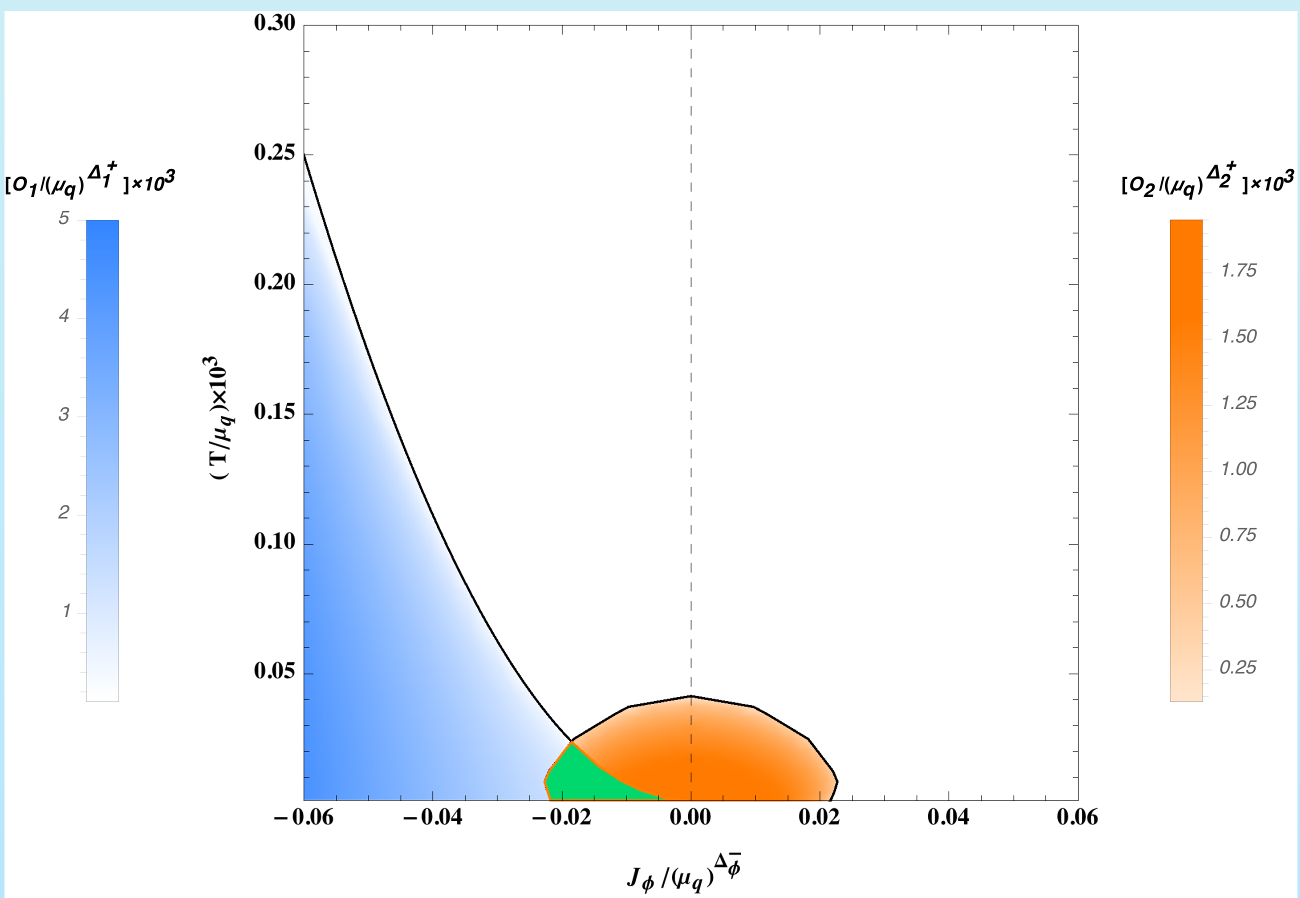
Presented by **Yun-Long Zhang**

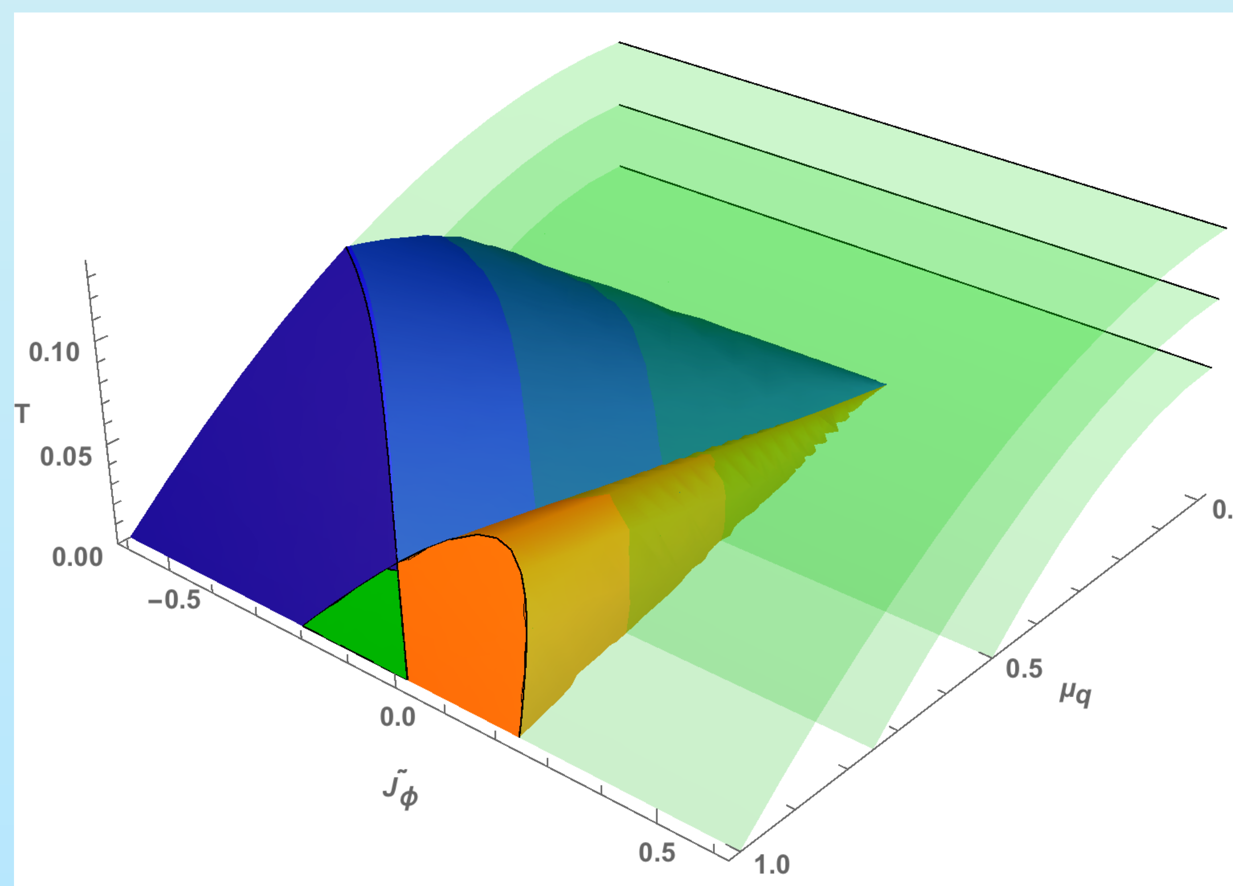
CTS-NTU (Center for Theoretical Sciences, National Taiwan University)

— zhangyunlong001@gmail.com 2016-06-15 @ YITP

$$\mathcal{L}_M = \sum_{i=1,2} \mathcal{L}_{\psi_i} + \mathcal{L}_\phi + \mathcal{L}_{int}, \qquad g_M^2 \mathcal{L}_{\psi_i} = -\frac{1}{2}\left(\partial\psi_i\right)^2 - V(\psi_i), \qquad V(\psi_i) = \frac{1}{2}m_i^2\psi_i^2 + \frac{1}{4}\lambda_i\psi_i^4,$$

$$g_M^2 \mathcal{L}_{int} = -\frac{1}{2}\sum_{i=1,2} F_i(\phi)\psi_i^2, \qquad g_M^2 \mathcal{L}_\phi = -\frac{1}{2}\left(\partial\phi\right)^2 - V(\phi), \qquad V(\phi) = \frac{1}{2}m_\phi^2\phi^2 + \frac{1}{4}\lambda_\phi\phi^4,$$

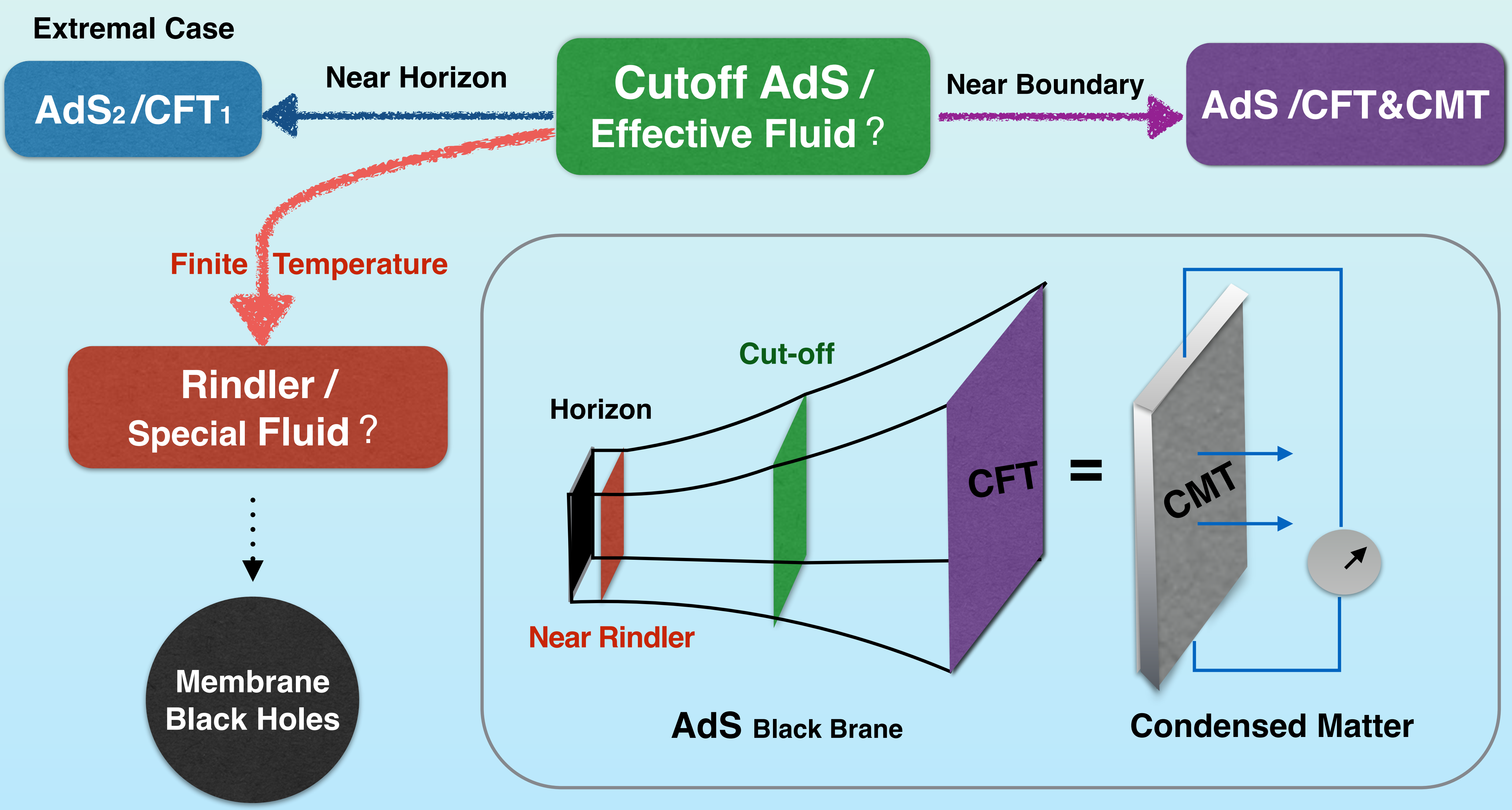




arXiv: [1603.08259] Jiunn-Wei Chen, Shou-Huang Dai, Debaprasad Maity, Yun-Long Zhang

Constraints in Rindler Fluid & AdS Cutoff Fluid

arXiv: 1207.5309 & 1401.7792 & 1408.6488



Presented by Yun-Long Zhang (zhangyunlong001@gmail.com)