Can we study real time dynamics of string theory?

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花田 政範

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Boulder → Southampton

July 2, 2018 @ YITP

QFT

Holography

=

Black Hole

Holography

QFT = Black Hole

For imaginary time, lattice simulation is powerful
and probably the only practical tool in generic situation.
(Enrico Rinaldi's talk next week)

(Euclidean simulation is nice)
but I want to know real time dynamics.
Lattice gauge theory doesn't work, does it?

(Joe Polchinski → MH, 2013)

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Challenge accepted

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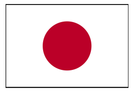
Challenge accepted

That was (not a challenge but) a wish list :).

(Joe Polchinski → MH, 2015)

We should consider all possibilities, not necessarily lattice gauge theory.

- Quantum simulation? **10-20 minutes**
- Classical Yang-Mills? **30-40 minutes**
- Classical Yang-Mills + quantum effect? **0-5 minutes**
- Or better ideas?

coffee break, or tonight before   **(3:00 am)**

Quantum Simulation?

Holography

QFT = Black Hole

‘the *other* world’

Our world with gravity

Let's make it in our world (almost) without gravity.

Holography

QFT = Black Hole

‘the *other* world’

Our world with gravity

‘Hamiltonian engineering’ on optical lattice

- A kind of problem-specific quantum simulation.
- Trap cold atoms by lasers and introduce appropriate interaction.
- Then Nature takes care of quantum time evolution.
- Perform measurement.

- Physical realization of a black hole.

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- Having actual physical one is (probably) more fun.

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BBC Sign in

NEWS

The Japanese men happy with 'virtual girlfriends'

Japanese women are having fewer babies than ever before - and if this continues, **by 2060 the population of the world's third largest economy will shrink by a third.** But are immature and commitment-averse Japanese men to blame?

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- Having actual physical one is (probably) more fun.

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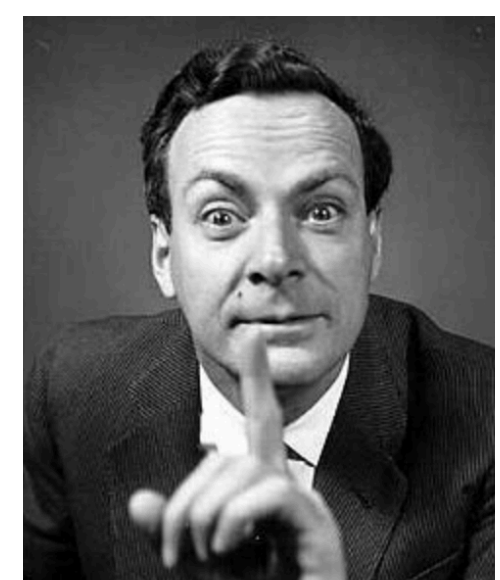
- What I cannot create, I do not understand.



Of course, Feynman did not literally mean to ‘create’.

‘What I cannot create, I do not understand.’

∼ derive

‘Know how to solve every problem that has been solved.’

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‘What I cannot create, I do not understand.’

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But how can we ‘solve’ QFT and get actual numbers?

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‘What I cannot create, I do not understand.’

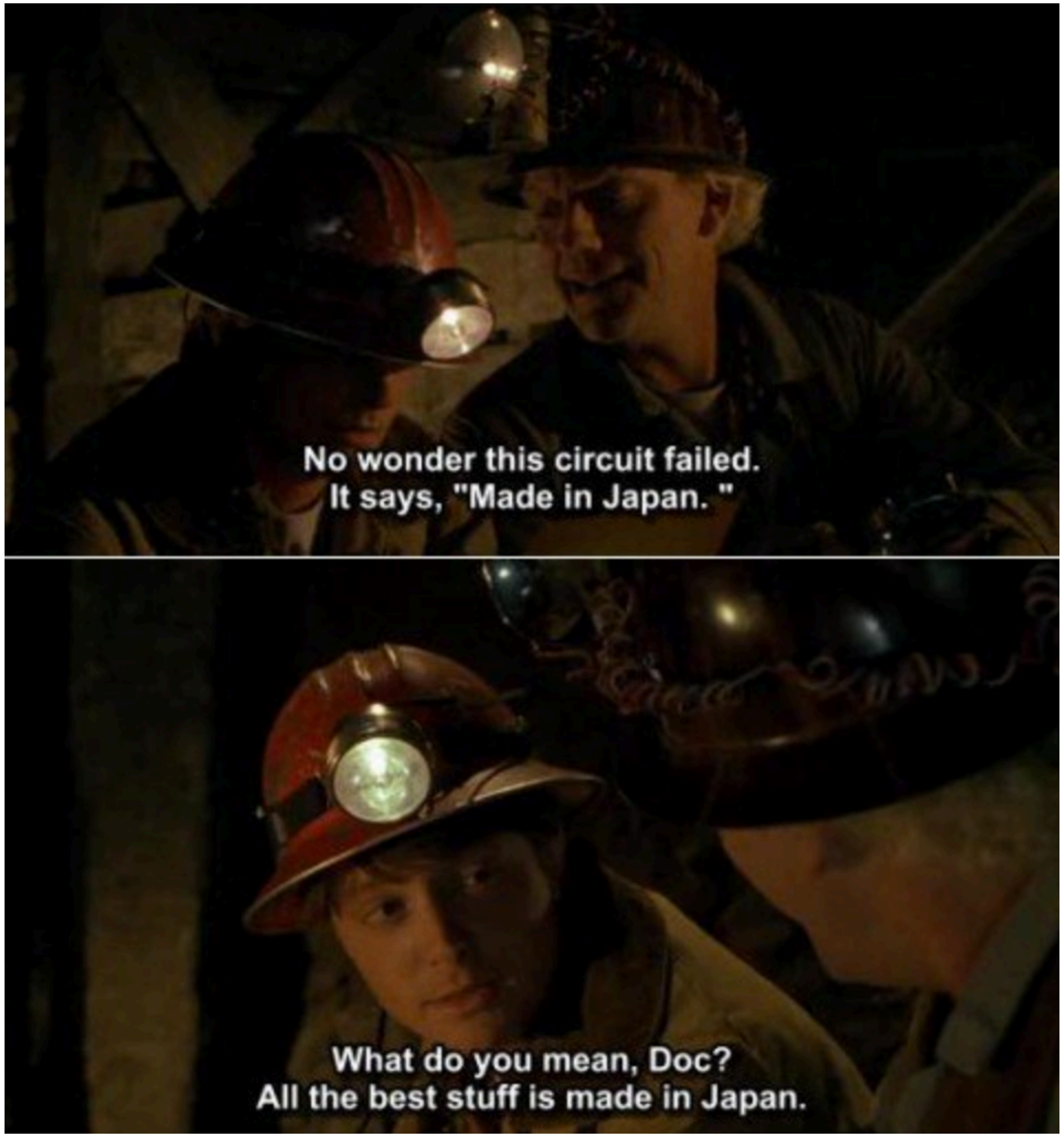
$\sim$ derive

‘Know how to solve every problem that has been solved.’

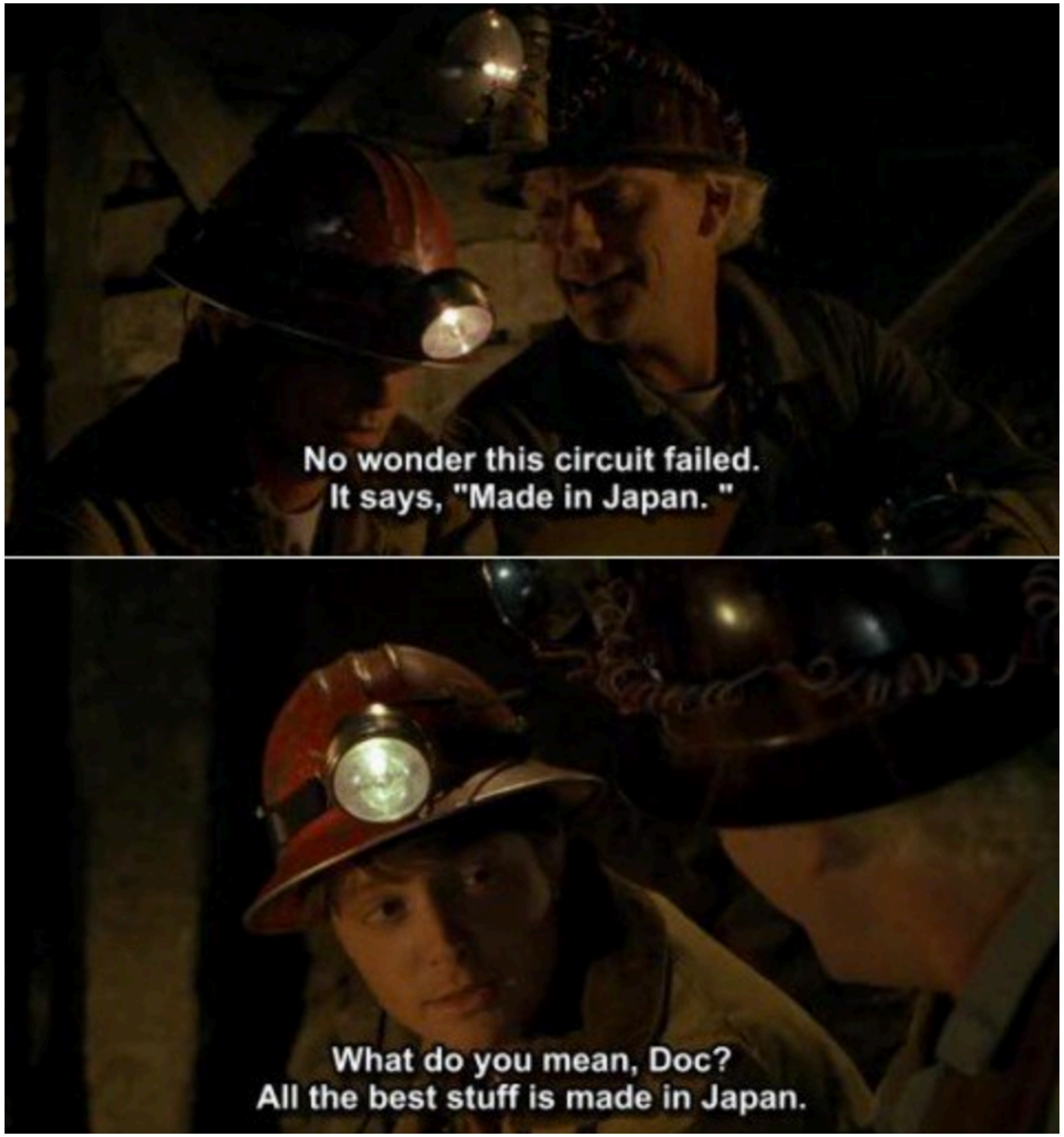
But how can we ‘solve’ QFT and get actual numbers?

Unless we create, we will not understand.

(Maybe.)



(Steven Spielberg, 1990)



(Steven Spielberg, 1990)


Wikipedia


Wikipedia


Wikipedia

I. Danshita (Kindai U.)

B. Sundborg
(Stockholm U.)

N. Wintergerst
(Niels Bohr Institute)

S. Nakajima M. Tezuka

(Kyoto U.)

(1) ‘In Principle’ realization of SYK

(Danshita, MH, Tezuka, 2016)

(2) More realistic realization of 3d Gross-Neveu

(Danshita, MH, Nakajima, Sundborg, Tezuka, Wintergerst, at very elementary stage)

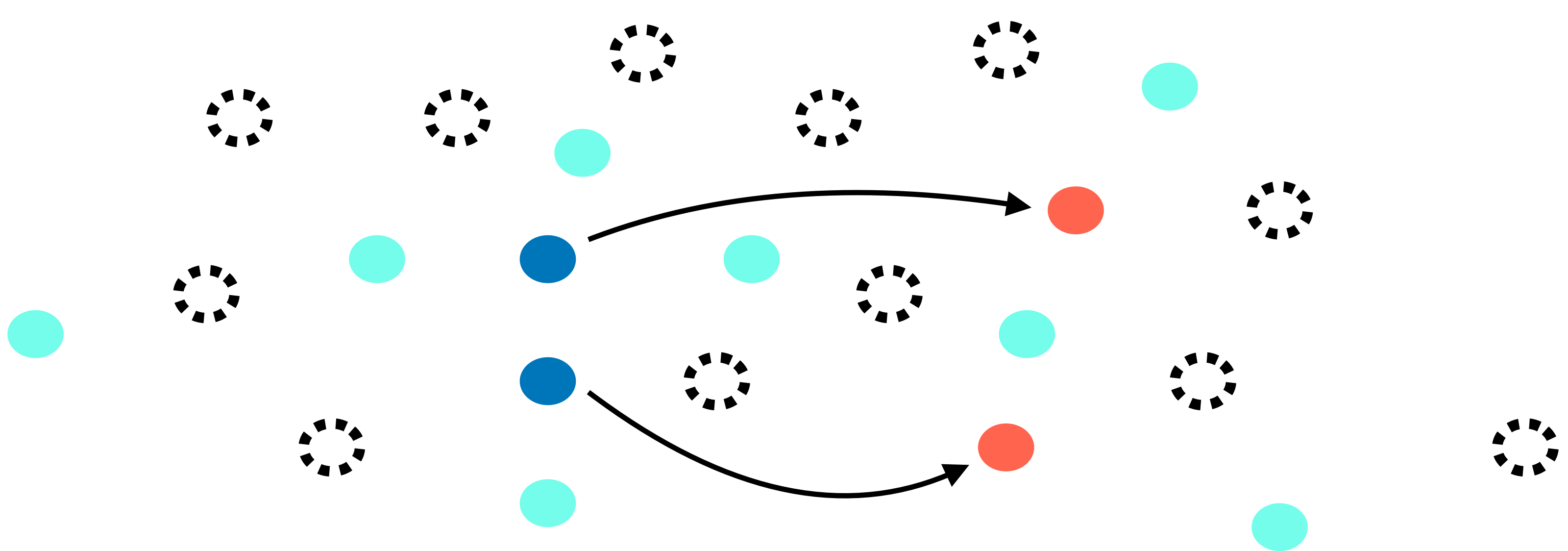
Complex SYK model

$$\hat{H} = \frac{1}{(2N)^{3/2}} \sum_{ijkl} J_{ij,kl} \hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

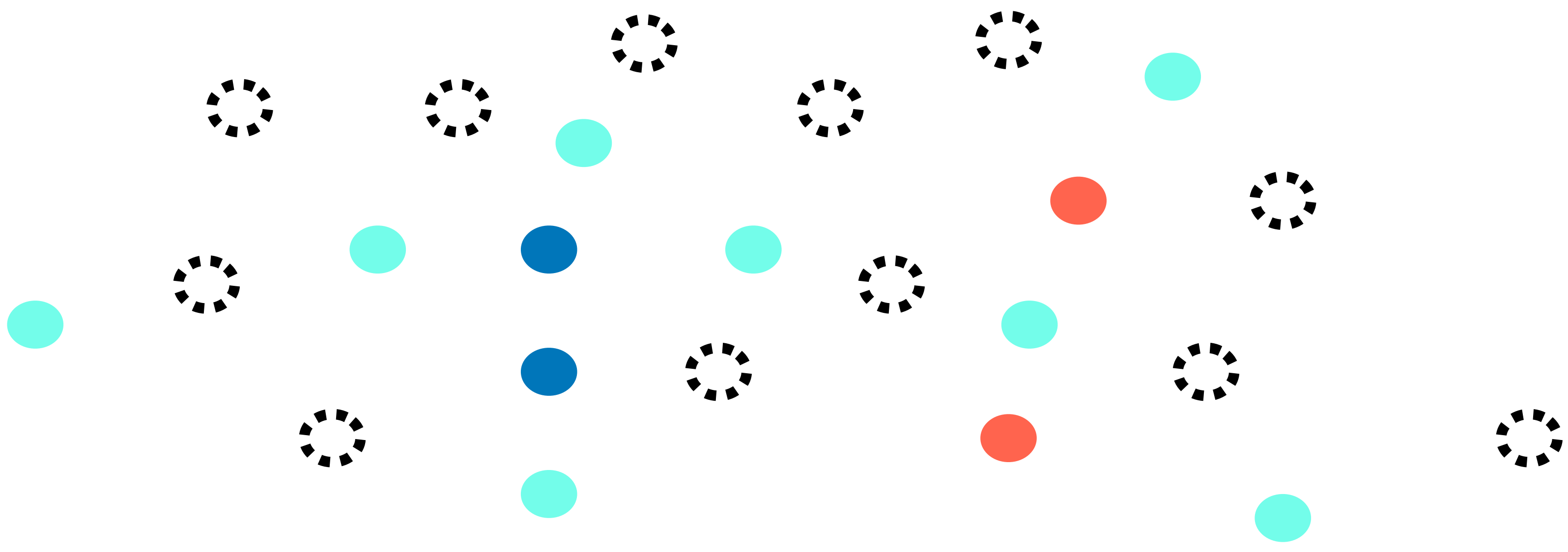
$$\{\hat{c}_i, \hat{c}_j\} = \{\hat{c}_i^\dagger, \hat{c}_j^\dagger\} = 0, \qquad \{\hat{c}_i^\dagger, \hat{c}_j\} = \delta_{ij}$$

$$J_{ij,kl} = -J_{ji,kl} = -J_{ij,lk}, \; J_{ij,kl} = J^*_{kl,ij}$$

Trap fermionic atoms in optical lattice and introduce appropriate interactions.



$$J_{ij,kl}\hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$



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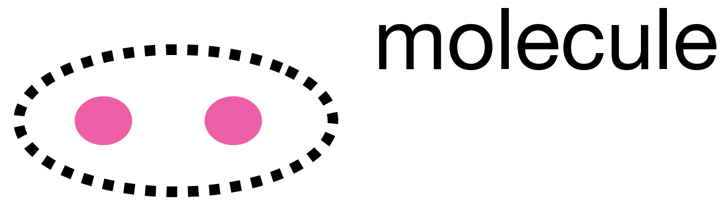
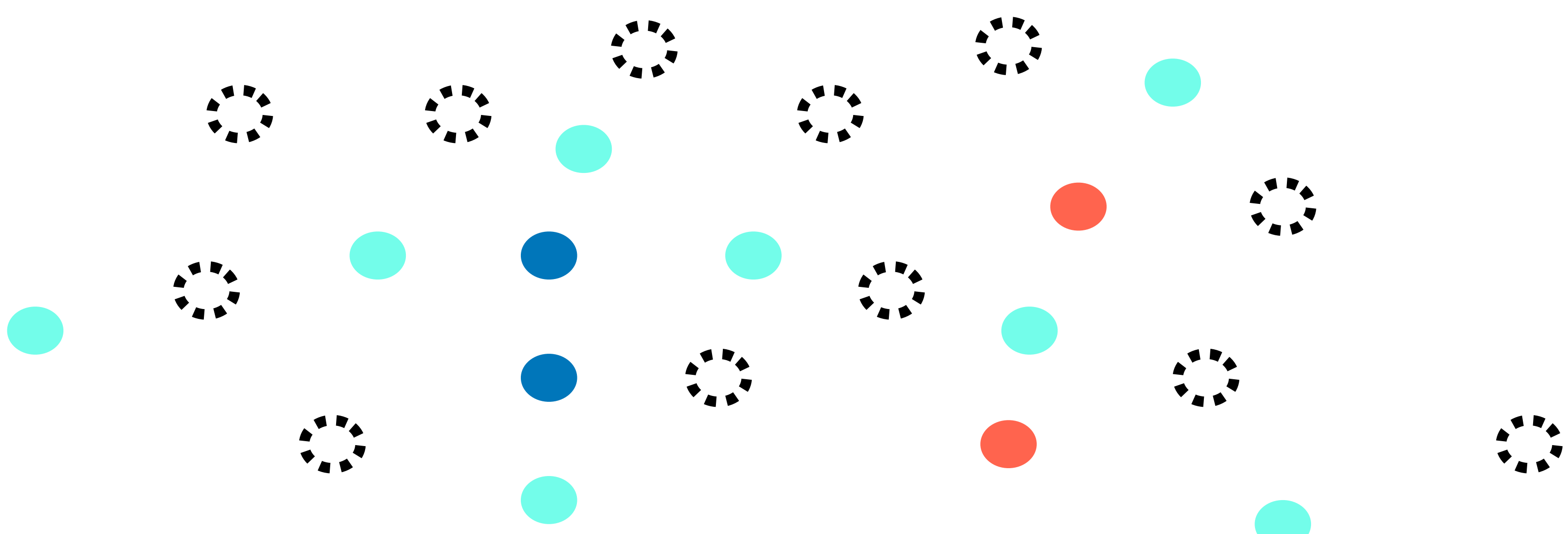
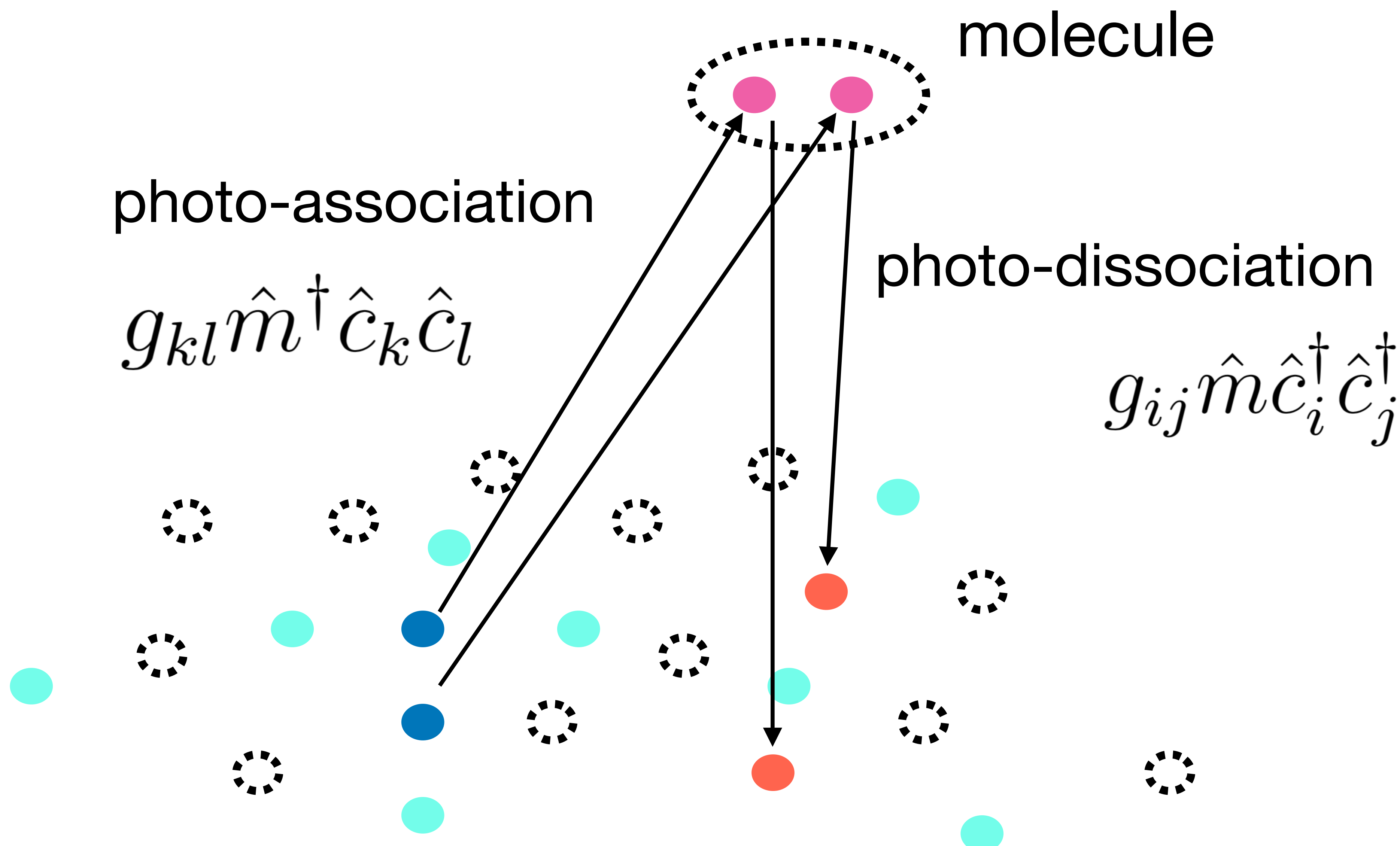
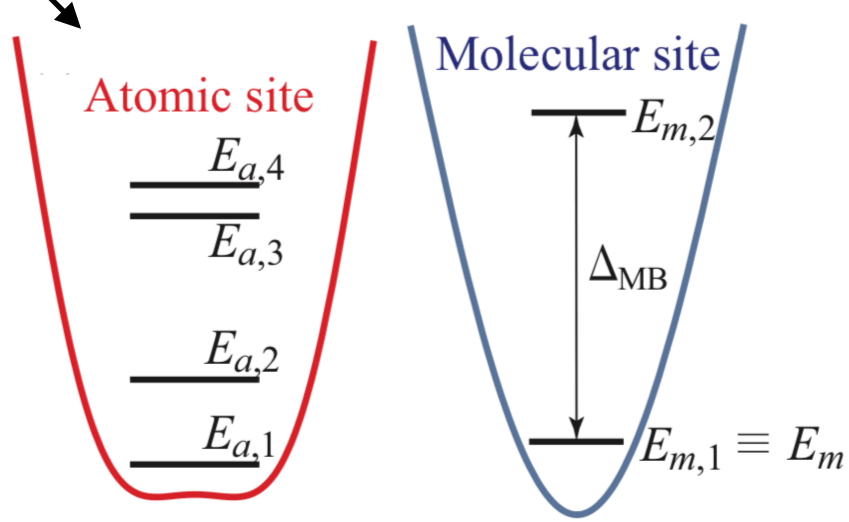


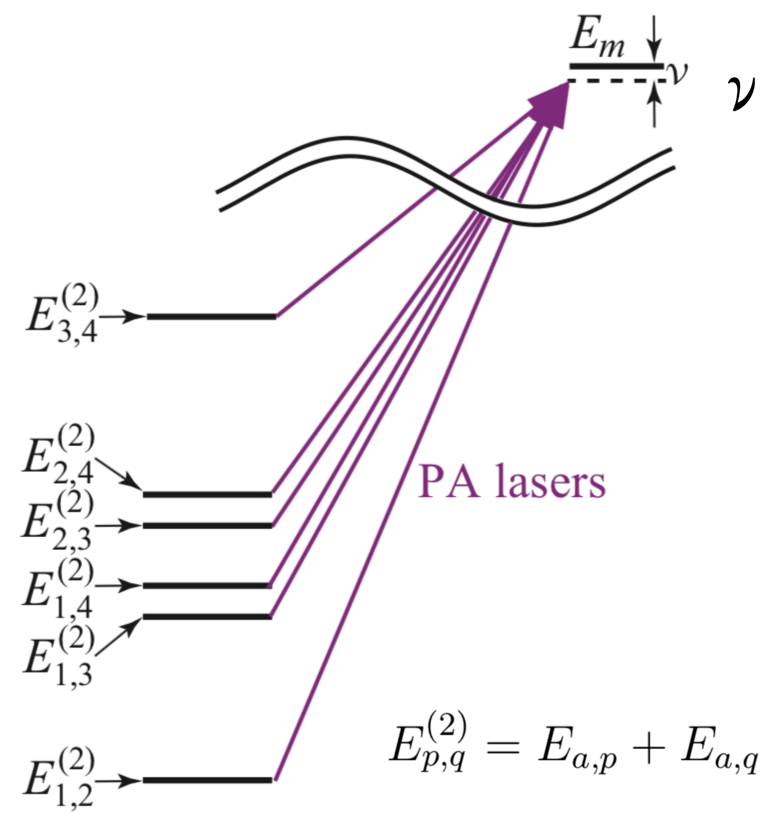


$$J_{ij,kl}\hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

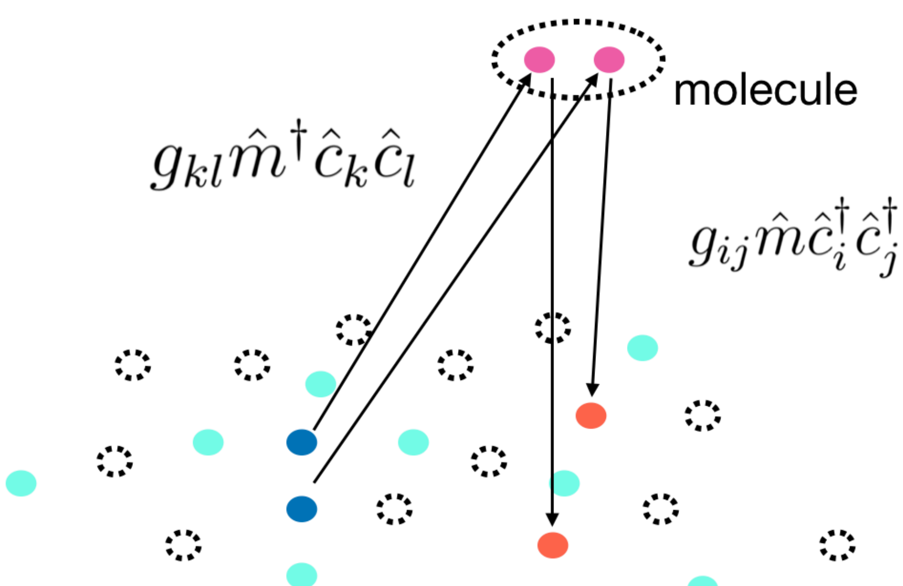


spin-polarized fermions
(no interaction)

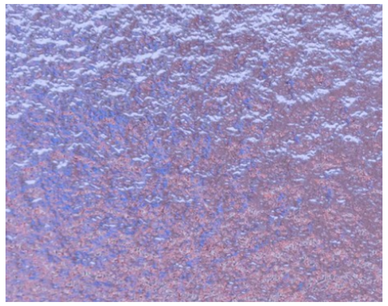




ν = ‘detuning’



$$\boxed{\frac{g_{ij}g_{kl}}{\nu}\hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l}$$



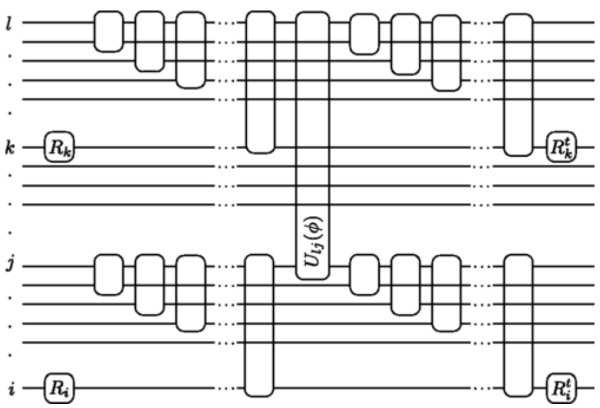
frosted glass
→ random g_{ij}

Multiple molecular states *s*

$$\sum_s \frac{g_{s,ij}g_{s,kl}}{\nu_s}\hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l \longrightarrow J_{ij,kl}\hat{c}_i^\dagger \hat{c}_j^\dagger \hat{c}_k \hat{c}_l$$

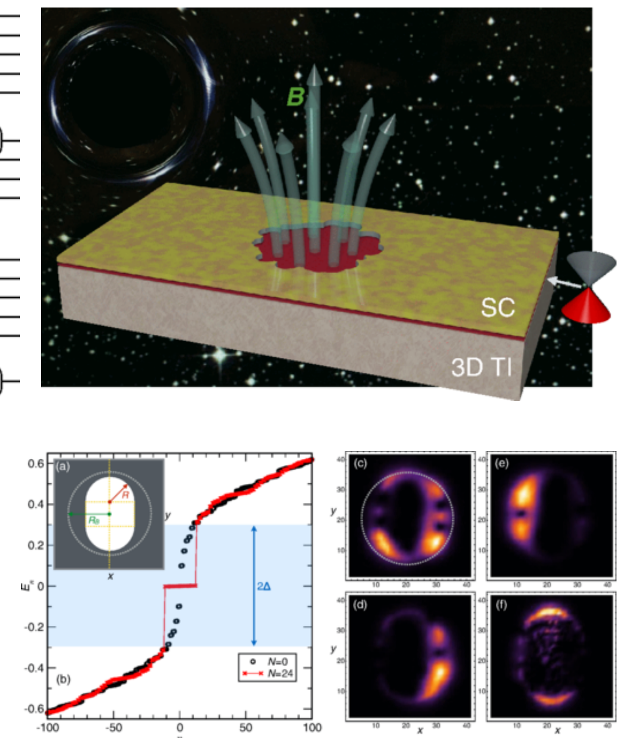
- In principle doable, but in practice, too many lasers are needed.
- There are several proposals by now.

arXiv:1607.08560



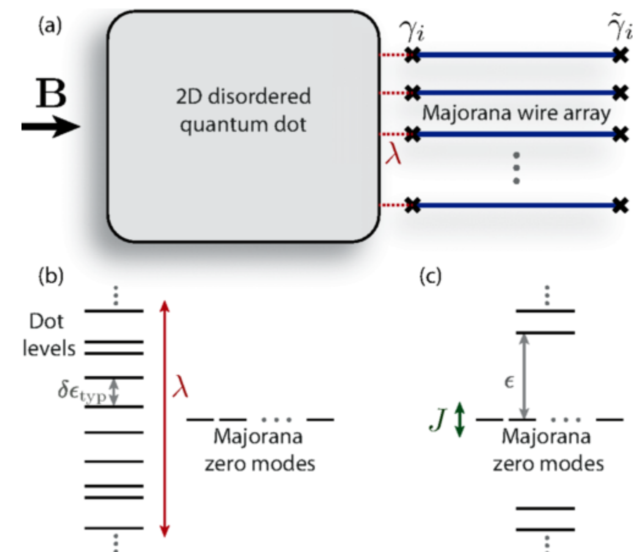
L. García-Álvarez, I. L. Egusquiza, L. Lamata, A. del Campo, J. Sonner, and E. Solano, “Digital Quantum Simulation of Minimal AdS/CFT”, PRL **119**, 040501 (2017)

arXiv:1702.04426



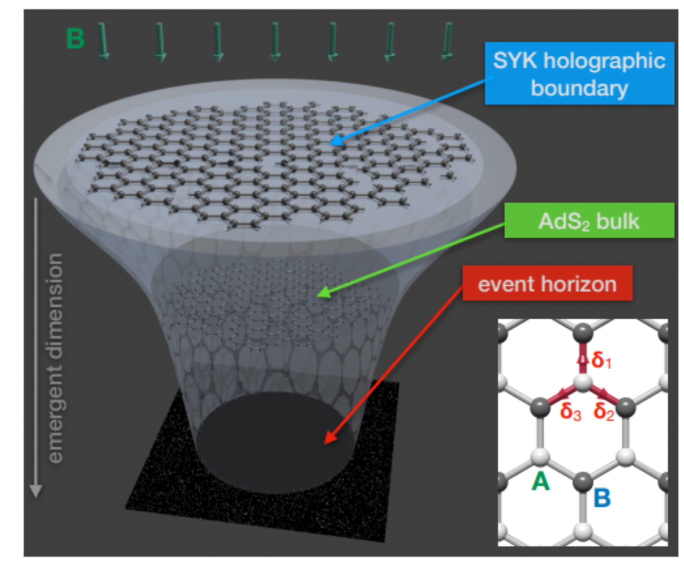
D. I. Pikulin and M. Franz, “Black Hole on a Chip: Proposal for a Physical Realization of the Sachdev-Ye-Kitaev model in a Solid-State System”, PRX **7**, 031006 (2017)

arXiv:1703.06890



Aaron Chew, Andrew Essin, and Jason Alicea, “Approximating the Sachdev-Ye-Kitaev model with Majorana wires”, PRB **96**, 121119(R) (2017)

arXiv:1802.00802



Anffany Chen, R. Ilan, F. de Juan, D.I. Pikulin, M. Franz, “Quantum holography in a graphene flake with an irregular boundary”, arXiv:1802.00802

- In principle doable, but in practice, too many lasers are needed.
- There are several proposals by now.
- Higher spin gravity may be a more tractable target.

SU(N) Gross-Neveu model

$$\mathcal{L} = i\bar{\psi}_a \partial\!\!\!/ \psi_a + \left(\bar{\psi}_a \psi_a\right)^2$$

SU(N) Hubbard model

$$\hat{H} = -t \sum_{\langle i,j \rangle} \sum_{a=1}^{N} \left(\hat{c}_{ia}^{\dagger} \hat{c}_{ja} + \hat{c}_{ja}^{\dagger} \hat{c}_{ia} \right) + U \sum_{i} \left(\sum_{a=1}^{N} \hat{c}_{ia}^{\dagger} \hat{c}_{ia} \right)^2$$

Hubbard on honeycomb lattice is believed to be 3d Gross-Neveu.

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tunable by changing the depth of potential

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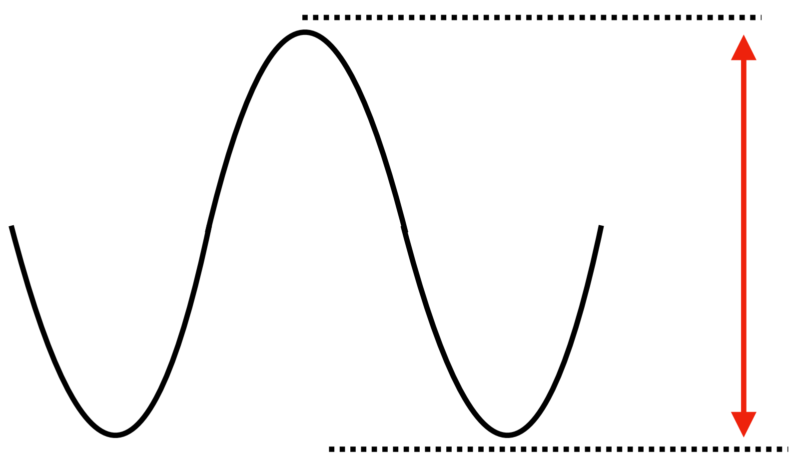


potential deep → less tunneling → small *t*

potential shallow → more tunneling → large *t*

potential deep →wave function more peaked → more overlap on the same site →large *U*

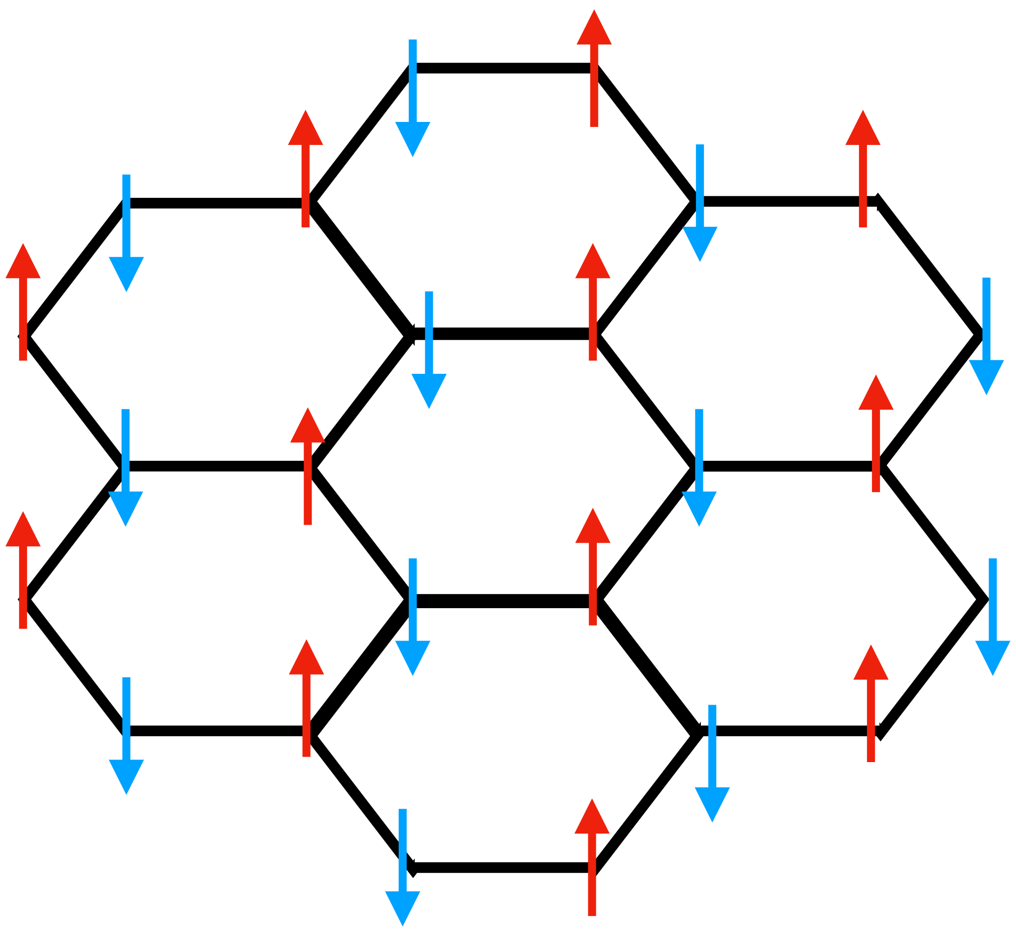
potential shallow →wave function spreads → less overlap on the same site →small *U*

U/*t* is tunable

SU(2)

‘half-filling’: $\#(\uparrow) = \#(\downarrow) = \#(\text{site})/2$

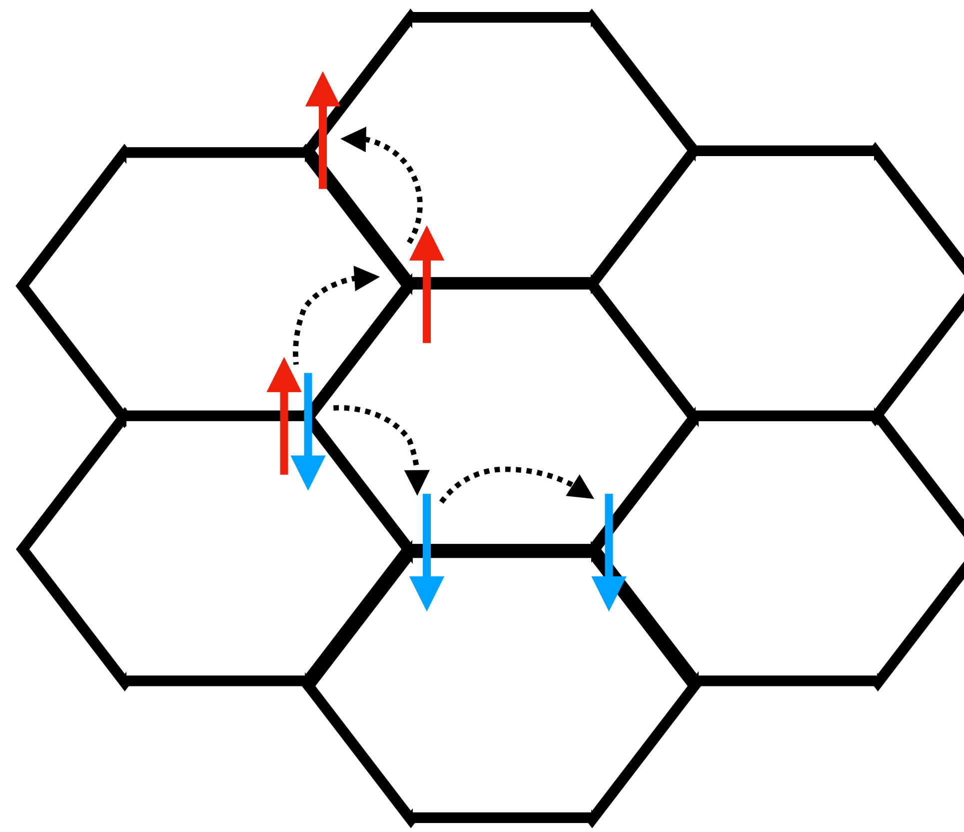
large U/t



anti-ferromagnet
spins cannot move

critical point
= Gross-Neveu

small U/t

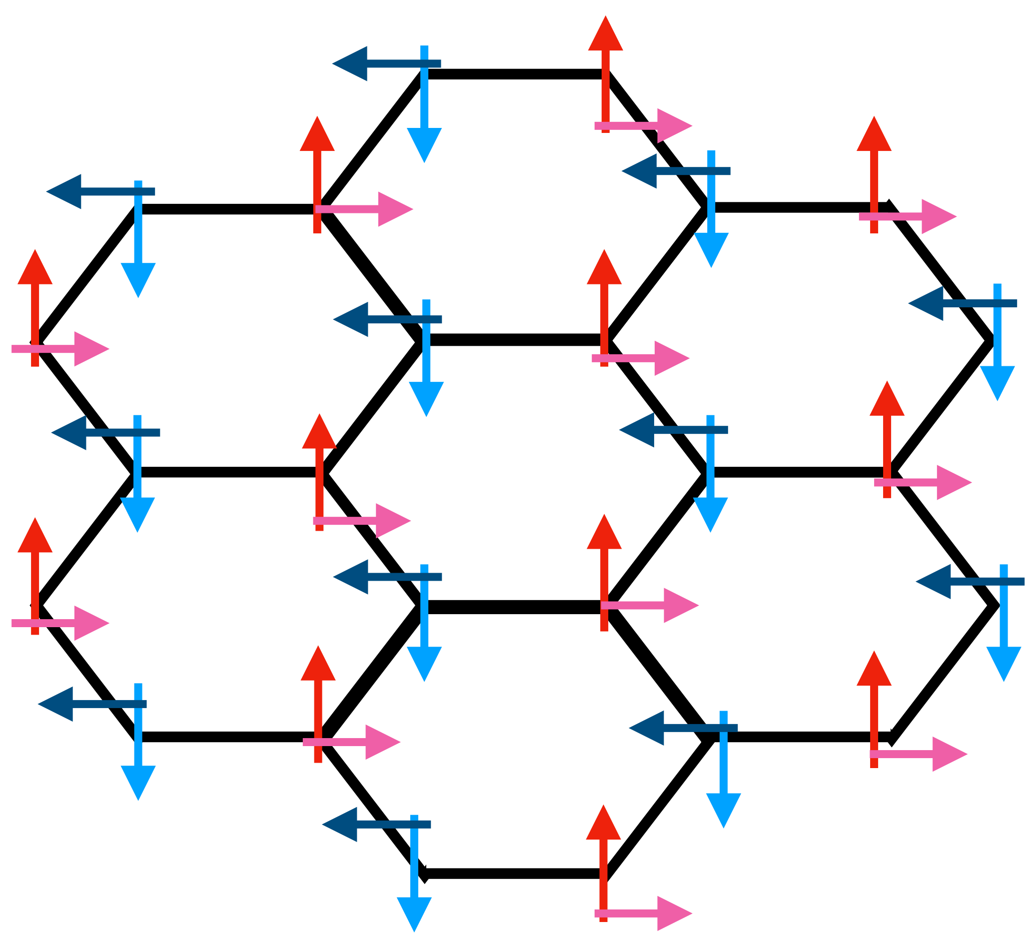


spins can move easily

SU(N)

‘half-filling’: $\#(c_1) = \ldots = \#(c_N) = \#(\text{site})/2$

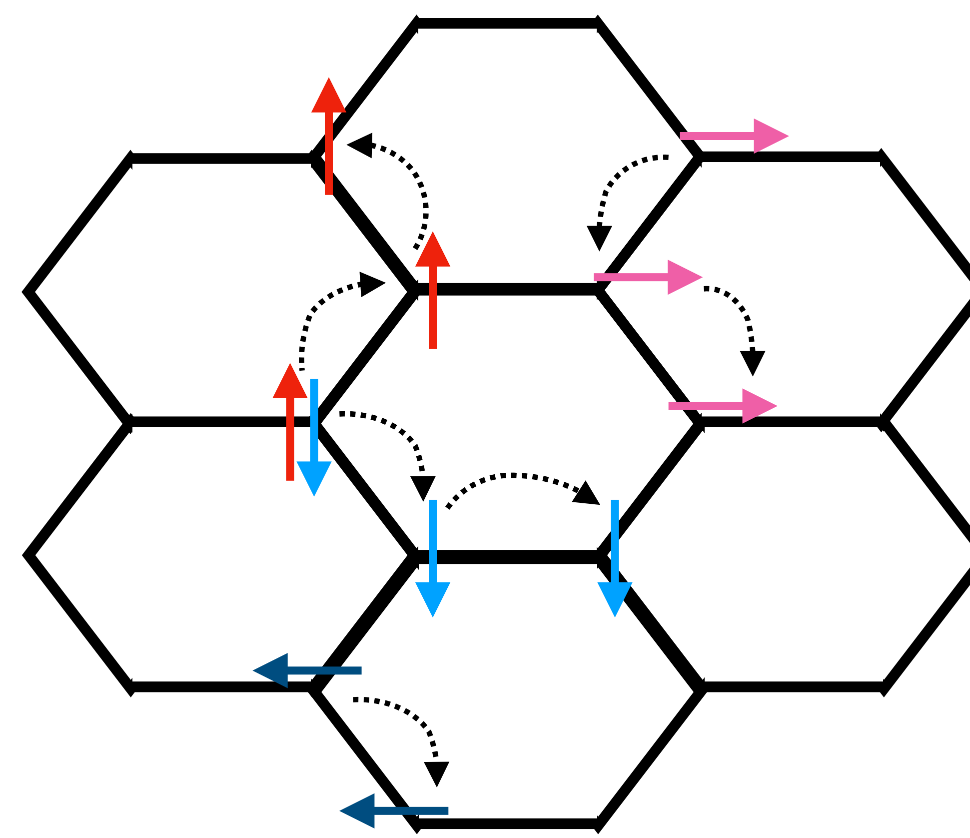
large U/t



anti-ferromagnet
spins cannot move

critical point
= Gross-Neveu

small U/t



spins can move easily

- SU(N) Hubbard Model is experimentally realized by now.
- Honeycomb optical lattice is also realized.

→ 3d Gross-Neveu is within reach?

Kyoto University
Department of Physics
Quantum Optics Group

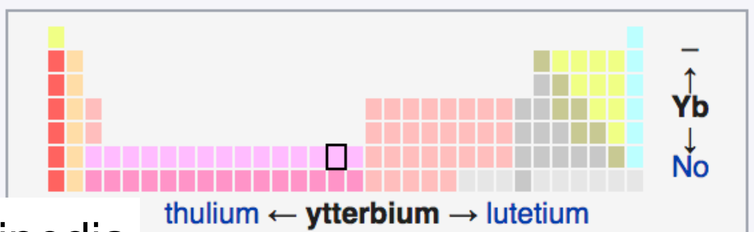
SU(N) ✔ honeycomb not yet

Ytterbium, $_{70}$Yb

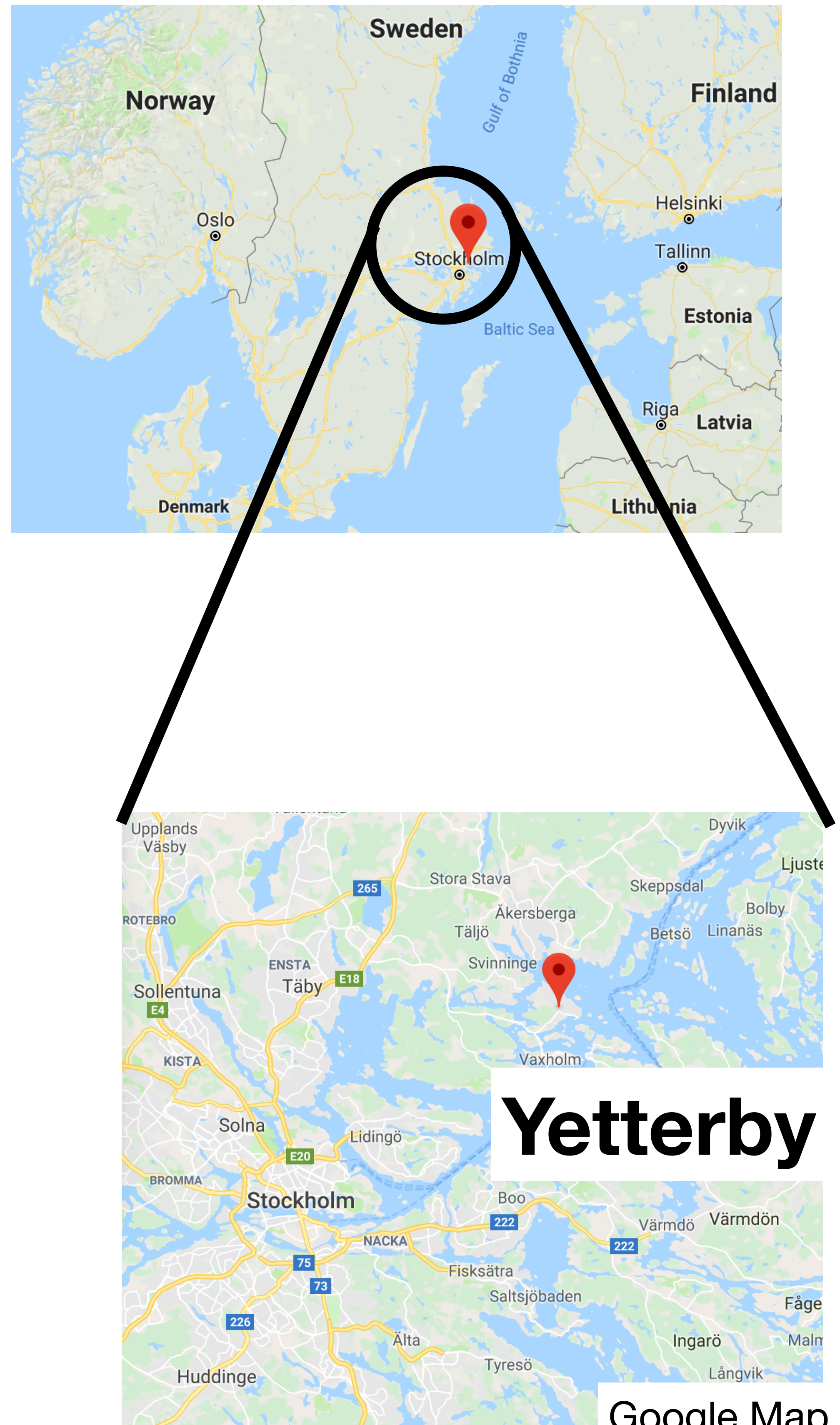
General properties

Pronunciation	/ɪˈtɜːrbiəm/ (*ih-TUR-bee-əm*)
Appearance	silvery white; with a pale yellow tint[1]
Standard atomic weight ($A_{r, standard}$)	173.045(10)[2][3][4]

Ytterbium in the periodic table



Wikipedia



Google Map

Isotopes of Ytterbium

Nuclide symbol	Z(p)	N(n)	Isotopic mass (u)	Half-life	Decay mode(s)[3][n 1]	Daughter isotope(s)[n 2]	Nuclear spin and parity	Representative isotopic composition (mole fraction)	Range of natural variation (mole fraction)
	Excitation energy								
^{148}Yb	70	78	147.96742(64)#	250# ms	β+	^{148}Tm	0+		
^{149}Yb	70	79	148.96404(54)#	0.7(2) s	β+	^{149}Tm	(1/2+,3/2+)		
^{150}Yb	70	80	149.95842(43)#	700# ms [>200 ns]	β+	^{150}Tm	0+		
^{151}Yb	70	81	150.95540(32)	1.6(5) s	β+	^{151}Tm	(1/2+)		
					β+, p (rare)	^{150}Er			
^{151m1}Yb	750(100)# keV			1.6(5) s	β+	^{151}Tm	(11/2−)		
					β+, p (rare)	^{150}Er			
^{151m2}Yb	1790(500)# keV			2.6(7) μs			19/2−#		
^{151m3}Yb	2450(500)# keV			20(1) μs			27/2−#		
^{152}Yb	70	82	151.95029(22)	3.04(6) s	β+	^{152}Tm	0+		
					β+, p (rare)	^{151}Er			
^{153}Yb	70	83	152.94948(21)#	4.2(2) s	α (50%)	^{149}Er	7/2−#		
					β+ (50%)	^{153}Tm			
					β+, p (.008%)	^{152}Er			
^{153m}Yb	2700(100) keV			15(1) μs			(27/2−)		
^{154}Yb	70	84	153.946394(19)	0.409(2) s	α (92.8%)	^{150}Er	0+		
					β+ (7.119%)	^{154}Tm			
^{155}Yb	70	85	154.945782(18)	1.793(19) s	α (89%)	^{151}Er	(7/2−)		
					β+ (11%)	^{155}Tm			
^{156}Yb	70	86	155.942818(12)	26.1(7) s	β+ (90%)	^{156}Tm	0+		
					α (10%)	^{152}Er			
^{157}Yb	70	87	156.942628(11)	38.6(10) s	β+ (99.5%)	^{157}Tm	7/2−		
					α (.5%)	^{153}Er			
^{158}Yb	70	88	157.939866(9)	1.49(13) min	β+ (99.99%)	^{158}Tm	0+		
					α (.0021%)	^{154}Er			
^{159}Yb	70	89	158.94005(2)	1.67(9) min	β+	^{159}Tm	5/2(−)		
^{160}Yb	70	90	159.937552(18)	4.8(2) min	β+	^{160}Tm	0+		
^{161}Yb	70	91	160.937902(17)	4.2(2) min	β+	^{161}Tm	3/2−		
^{162}Yb	70	92	161.935768(17)	18.87(19) min	β+	^{162}Tm	0+		
^{163}Yb	70	93	162.936334(17)	11.05(25) min	β+	^{163}Tm	3/2−		
^{164}Yb	70	94	163.934489(17)	75.8(17) min	EC	^{164}Tm	0+		
^{165}Yb	70	95	164.93528(3)	9.9(3) min	β+	^{165}Tm	5/2−		
^{166}Yb	70	96	165.933882(9)	56.7(1) h	EC	^{166}Tm	0+		
^{167}Yb	70	97	166.934950(5)	17.5(2) min	β+	^{167}Tm	5/2−		
^{168}Yb	70	98	167.933897(5)	Observationally Stable[n 3]			0+	0.0013(1)	
^{169}Yb	70	99	168.935190(5)	32.026(5) d	EC	**^{169}Tm**	7/2+		
^{169m}Yb	24.199(3) keV			46(2) s	IT	^{169}Yb	1/2−		
^{170}Yb	70	100	169.9347618(26)	**Observationally Stable**[n 4]			0+	0.0304(15)	
^{170m}Yb	1258.46(14) keV			370(15) ns			4−		
^{171}Yb	70	101	170.9363258(26)	**Observationally Stable**[n 5]			1/2−	0.1428(57)	
^{171m1}Yb	95.282(2) keV			5.25(24) ms	IT	^{171}Yb	7/2+		
^{171m2}Yb	122.416(2) keV			265(20) ns			5/2−		
^{172}Yb	70	102	171.9363815(26)	**Observationally Stable**[n 6]			0+	0.2183(67)	
^{173}Yb	70	103	172.9382108(26)	**Observationally Stable**[n 7]			5/2−	0.1613(27)	
^{173m}Yb	398.9(5) keV			2.9(1) μs			1/2−		
^{174}Yb	70	104	173.9388621(26)	**Observationally Stable**[n 8]			0+	0.3183(92)	
^{175}Yb	70	105	174.9412765(26)	4.185(1) d	β−	**^{175}Lu**	7/2−		
^{175m}Yb	514.865(4) keV			68.2(3) ms			1/2−		
^{176}Yb	70	106	175.9425717(28)	**Observationally Stable**[n 9]			0+	0.1276(41)	
^{176m}Yb	1050.0(3) keV			11.4(3) s			(8)−		
^{177}Yb	70	107	176.9452608(28)	1.911(3) h	β−	^{177}Lu	(9/2+)		
^{177m}Yb	331.5(3) keV			6.41(2) s	IT	^{177}Yb	(1/2−)		
^{178}Yb	70	108	177.946647(11)	74(3) min	β−	^{178}Lu	0+		
^{179}Yb	70	109	178.95017(32)#	8.0(4) min	β−	^{179}Lu	(1/2−)		
^{180}Yb	70	110	179.95233(43)#	2.4(5) min	β−	^{180}Lu	0+		
^{181}Yb	70	111	180.95615(43)#	1# min	β−	^{181}Lu	3/2−#		
^{182}Yb[n 10]	70	112		> 160 ns	β−	^{182}Lu	0+		

(Wikipedia)

stable, spin 5/2 ⟶ SU(6)

- SU(2), SU(4), SU(6), SU(8), SU(10) are doable with Strontium etc

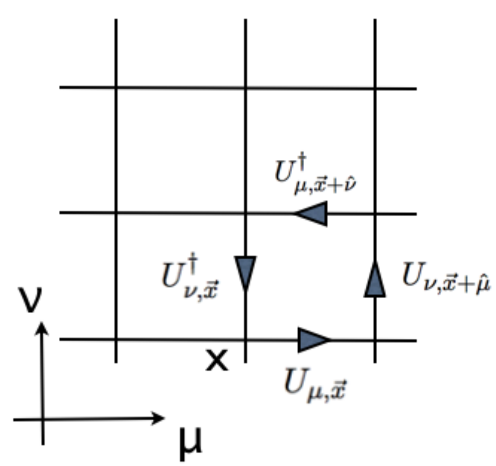
Lattice gauge theory on optical lattice?

Cirac (Max Planck), Zoller (Innsbruck), Wiese (Bern), Reznik (Tel Aviv), …

- (try to) construct Kogut-Susskind Hamiltonian

  Kogut-Susskind, 1974

- hard to implement matrix d.o.f.
- but let's stay tuned.



$$[E^\alpha_{\mu,\vec{x}}, U_{\nu,\vec{y}}] = \delta_{\mu\nu}\delta_{\vec{x}\vec{y}} \cdot \tau^\alpha U_{\nu,\vec{y}},$$
$$[E_{\mu,\vec{x}}, E_{\nu,\vec{y}}] = [U_{\mu,\vec{x}}, U_{\nu,\vec{y}}] = [U_{\mu,\vec{x}}, U^\dagger_{\nu,\vec{y}}] = 0.$$

μ, ν = x,y,z

- Quantum simulation?
- Classical Yang-Mills?
- Classical Yang-Mills + quantum effect?
- Or better ideas?

Aoki-MH-Iizuka, JHEP 2015
Gur Ari-MH-Shenker, JHEP 2016
Berkowitz-MH-Maltz, PRD 2016
MH-Romatschke, in preparation

A

B

I

R

G

M

S

- In AdS/CFT, weak and strong couplings are often very similar.
- D0, D1, D2: weak coupling $\sim$ high temperature;

  classical simulation can be useful.
- Studies of classical D0-brane matrix model suggested it is

  useful at least for thermalization and equilibrium physics.

Asplund, Berenstein, Trancanelli,..., 2011—

D0-brane quantum mechanics

$$S = \frac{N}{\lambda}\int_0^{\beta=1/T} dt\ Tr\Big\{\frac{1}{2}(D_tX_i)^2 - \frac{1}{4}[X_i,X_j]^2$$

$$+\frac{1}{2}\bar{\psi}D_t\psi - \frac{1}{2}\bar{\psi}\gamma^i[X_i,\psi]\Big\}$$

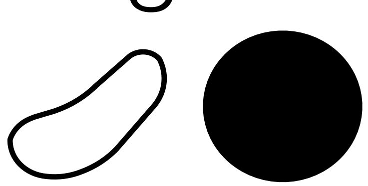
negligible at high-T

(dimensional reduction of 4d N=4 SYM)

effective dimensionless temperature $T_{eff} = \lambda^{-1/3}T$

($\lambda^{-1/2}T$ for D1, $\lambda^{-1}T$ for D2)

high-T = weak coupling = stringy (large α' correction)

string  BH

$$L = \frac{1}{2g_{YM}^2}\mathrm{Tr}\left(\sum_i (D_t X^i)^2 + \frac{1}{2}\sum_{i\neq j}[X_i, X_j]^2\right)$$

$$\longrightarrow \begin{cases} \dfrac{d^2 X^i}{dt^2} - \displaystyle\sum_j [X^j, [X^i, X^j]] = 0 \\ \displaystyle\sum_i \left[X^i, \frac{dX^i}{dt}\right] = 0 \quad \text{(A=0 gauge)} \end{cases}$$

discretize & solve it numerically.

black *p*-brane solution

(Horowitz-Strominger 1991)

$$ds^2 = \alpha' \left\{ \frac{U^{\frac{7-p}{2}}}{g_{YM}\sqrt{d_p N}} \left[-\left(1 - \frac{U_0^{7-p}}{U^{7-p}}\right) dt^2 + \sum_{i=1}^{p} dy_i^2 \right] + \frac{g_{YM}\sqrt{d_p N}}{U^{\frac{7-p}{2}}\left(1 - \frac{U_0^{7-p}}{U^{7-p}}\right)} dU^2 + g_{YM}\sqrt{d_p N} U^{\frac{p-3}{2}} d\Omega_{8-p}^2 \right\},$$

$$e^{\phi} = (2\pi)^{2-p} g_{YM}^2 \left(\frac{g_{YM}^2 d_p N}{U^{7-p}} \right)^{\frac{3-p}{4}}, \qquad d_p = 2^{7-2p} \pi^{\frac{9-3p}{2}} \Gamma\left(\frac{7-p}{2}\right),$$

$$T_{D0} = \frac{7}{4\pi\sqrt{d_0 \lambda}} U_0^{\frac{5}{2}}$$

black p-brane solution

(Horowitz-Strominger 1991)

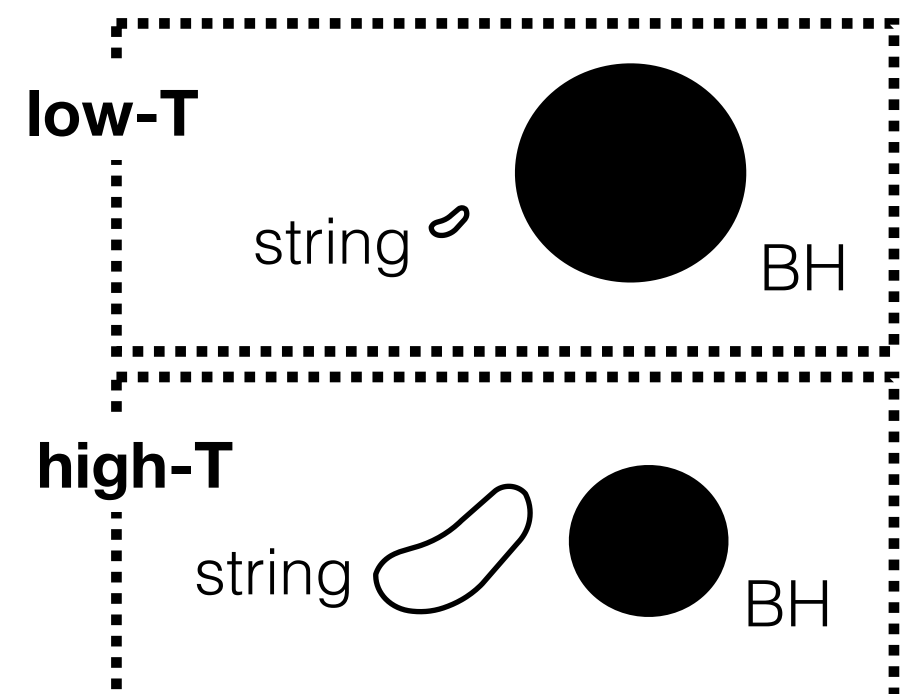
$$ds^2 = \alpha' \left\{ \frac{U^{\frac{7-p}{2}}}{g_{YM}\sqrt{d_p N}} \left[-\left(1 - \frac{U_0^{7-p}}{U^{7-p}}\right) dt^2 + \sum_{i=1}^{p} dy_i^2 \right] + \frac{g_{YM}\sqrt{d_p N}}{U^{\frac{7-p}{2}}\left(1 - \frac{U_0^{7-p}}{U^{7-p}}\right)} dU^2 + g_{YM}\sqrt{d_p N} U^{\frac{p-3}{2}} d\Omega_{8-p}^2 \right\},$$

>>1 at U=U_0 for low-T

$$e^{\phi} = (2\pi)^{2-p} g_{YM}^2 \left(\frac{g_{YM}^2 d_p N}{U^{7-p}} \right)^{\frac{3-p}{4}}, \qquad d_p = 2^{7-2p} \pi^{\frac{9-3p}{2}} \Gamma\left(\frac{7-p}{2}\right),$$

<< 1 at 't Hooft large N limit

$$T_{D0} = \frac{7}{4\pi\sqrt{d_0 \lambda}} U_0^{\frac{5}{2}}$$



Matrix Model 101

- Flat directions at classical level $[X_M, X_{M'}] = 0$
- Lifted by quantum effect (when fermion is negligible)

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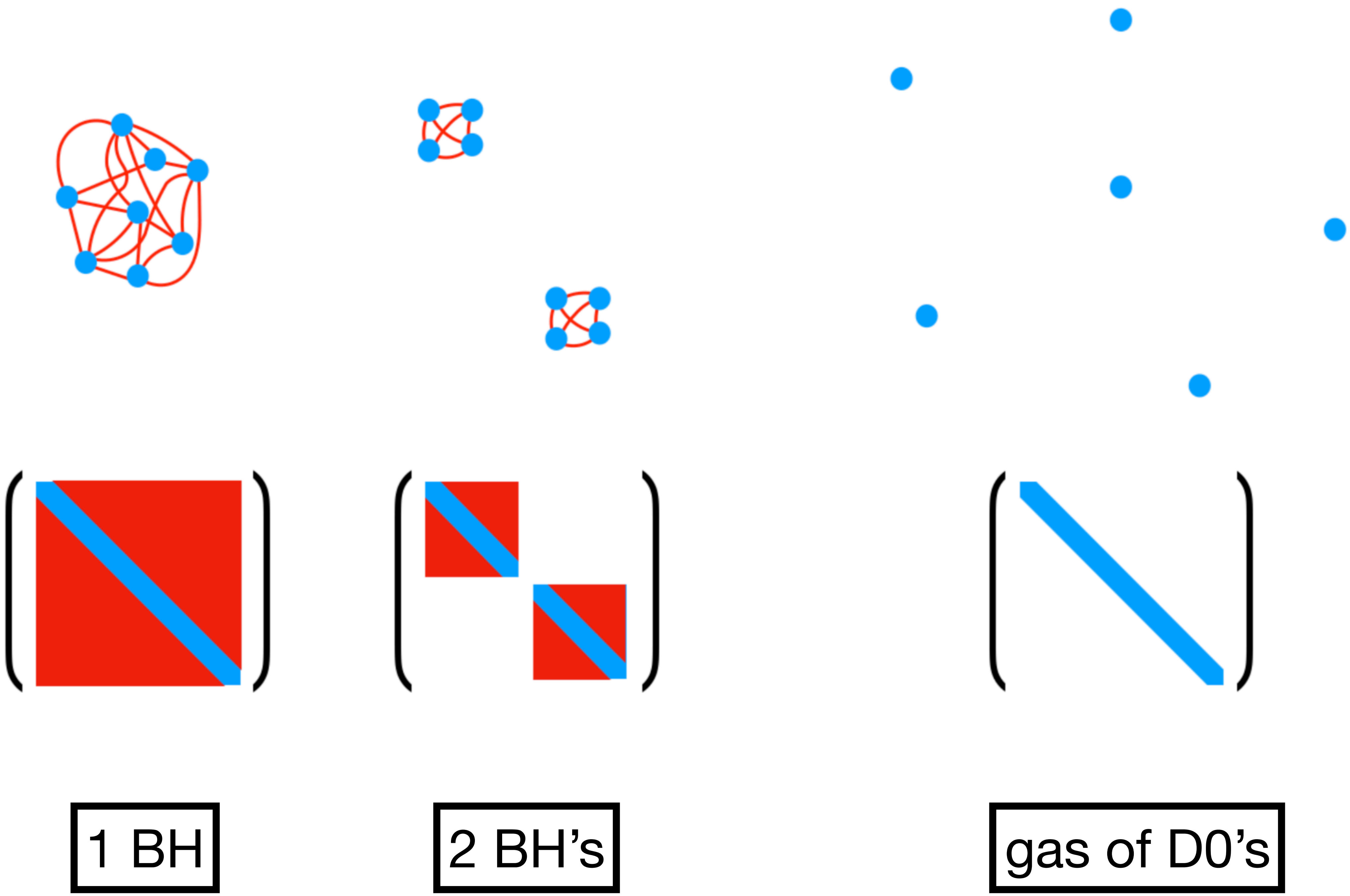
Flat direction is measure zero already in the classical theory

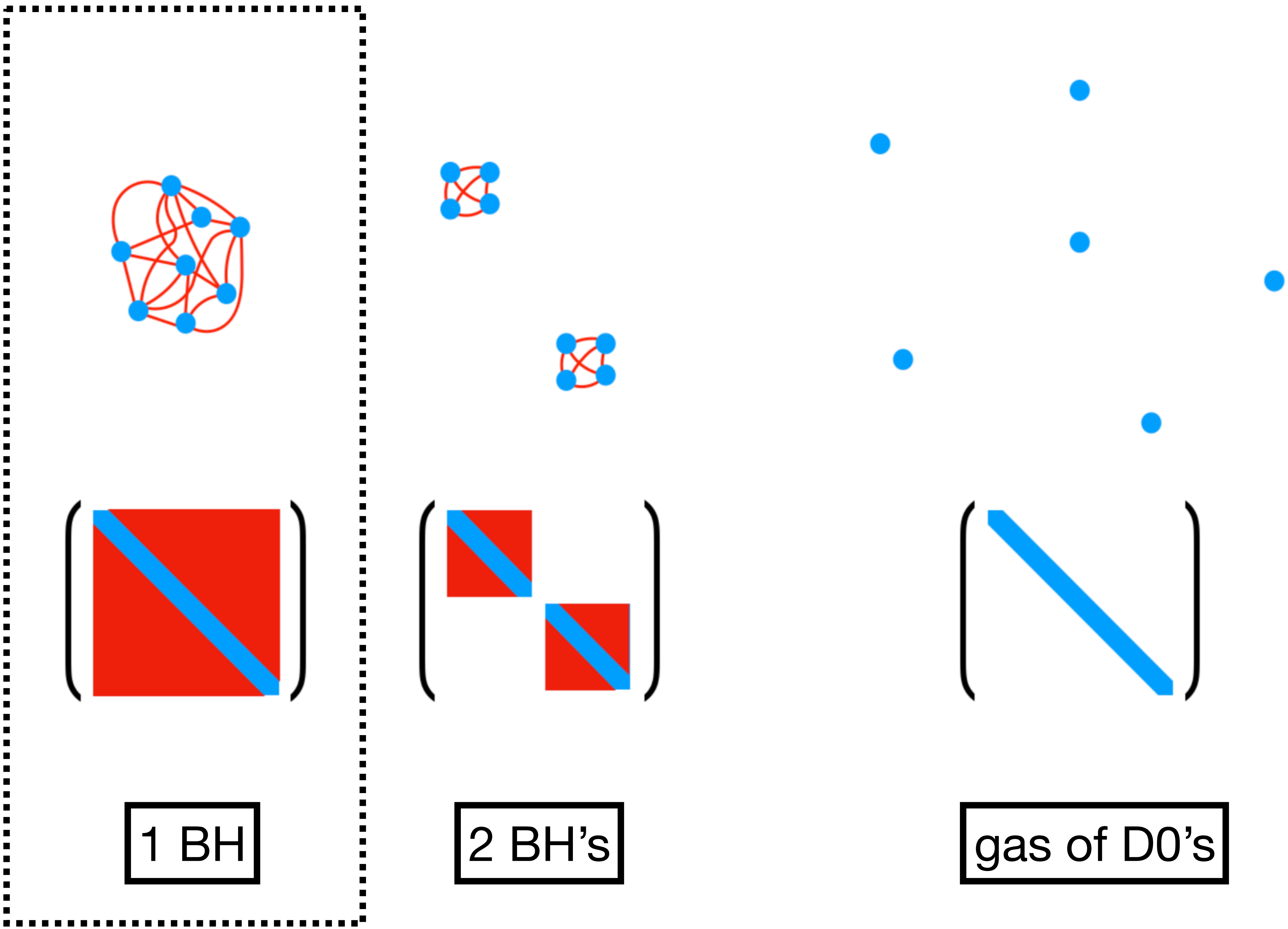
(Gur Ari-MH-Shenker; Berkowitz-MH-Maltz)

(also, probably D. Berenstein knew it)

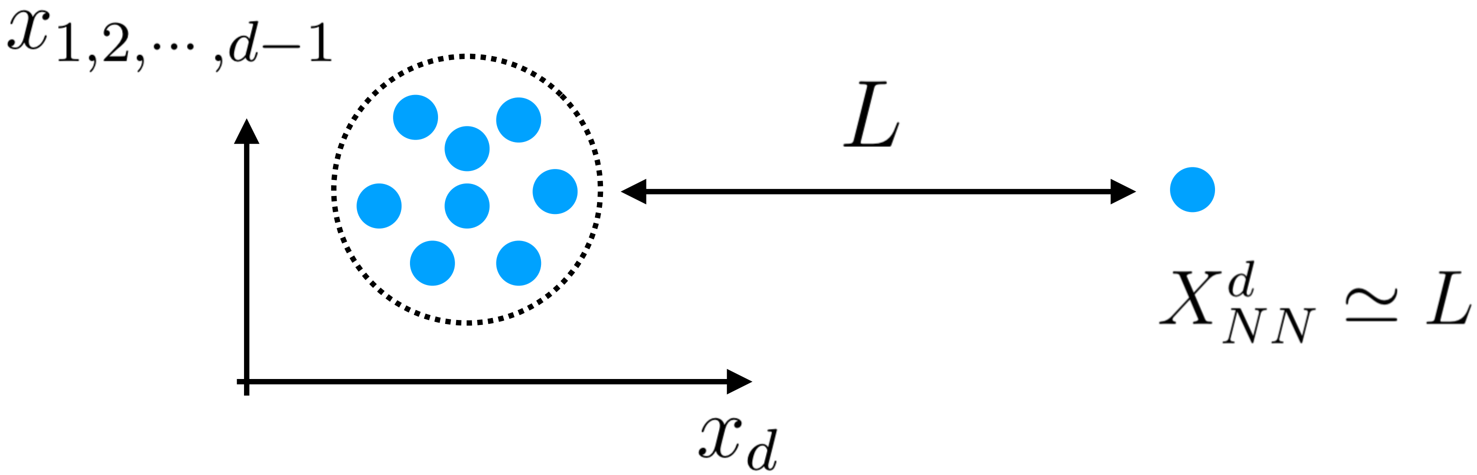


1 BH
2 BH's
gas of D0's

Let's study this one.



Why no flat direction?



energy of *N*-th row & column $\sim \frac{1}{g^2} \sum_{i=1}^{d-1} \sum_{a=1}^{N-1} L^2 |X^i_{aN}|^2$

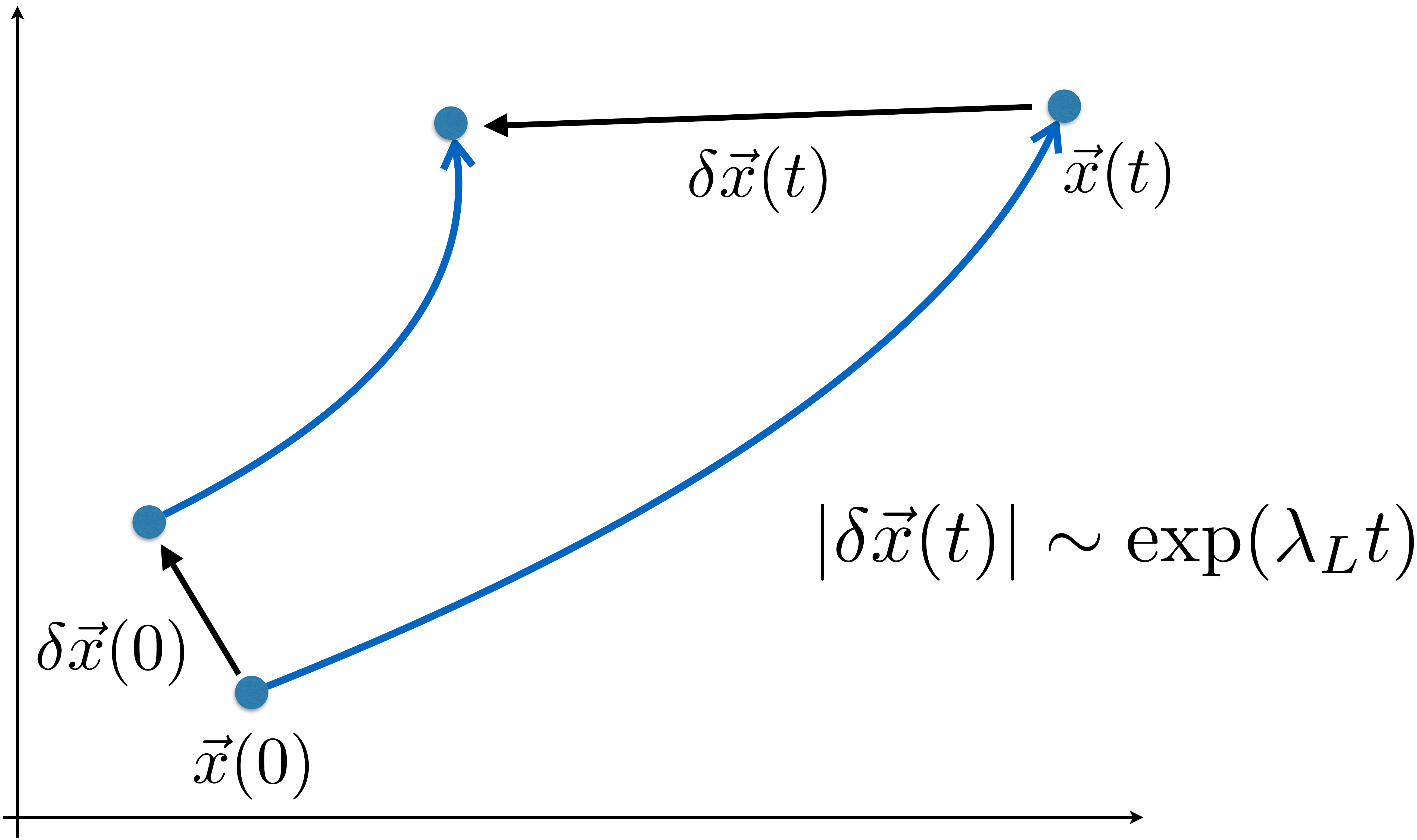
phase space suppression $\sum_{i=1}^{d-1} \sum_{a=1}^{N-1} |X^i_{aN}|^2 \lesssim g^2 E / L^2$

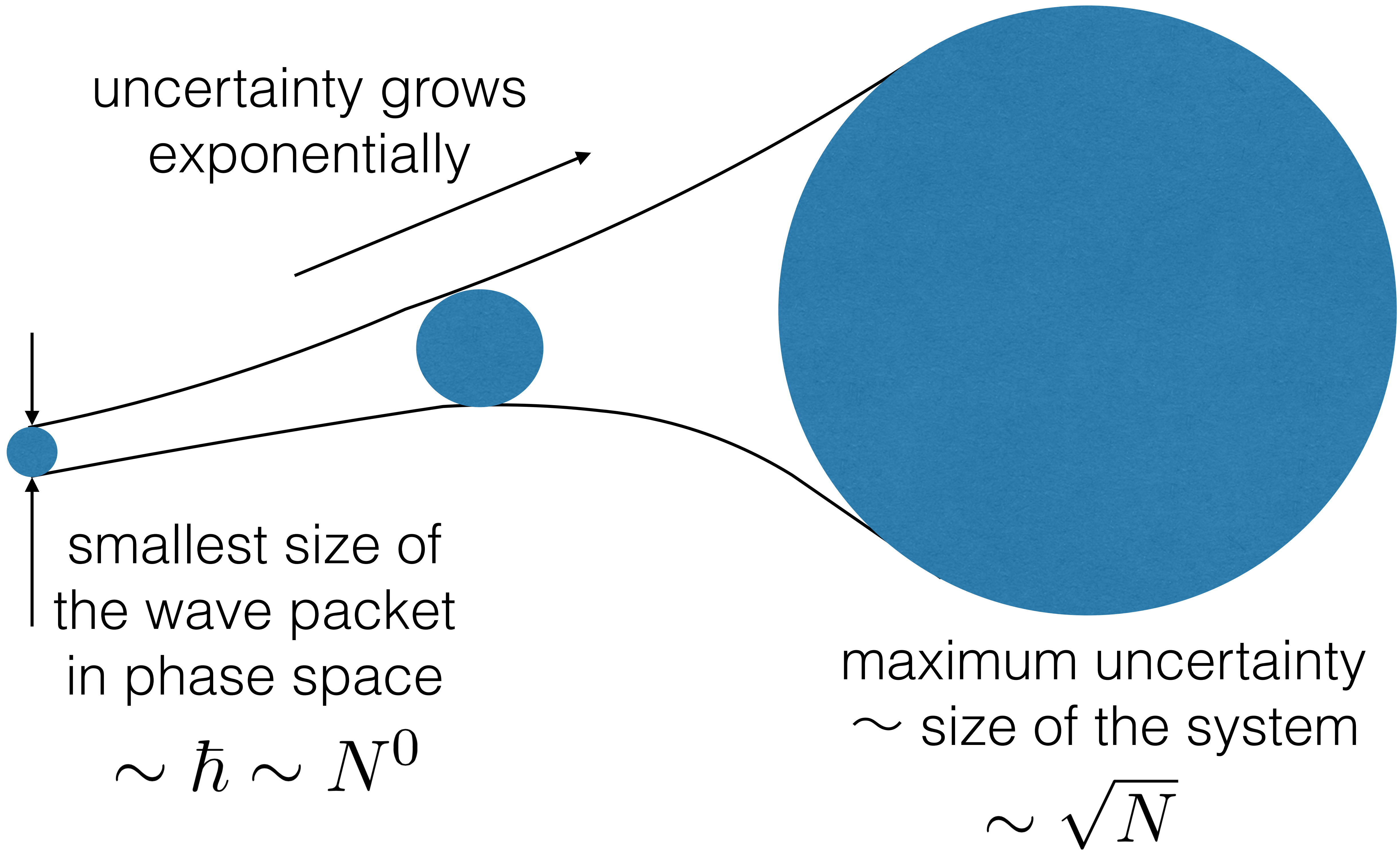
phase space volume at $L > L_0$

$$\int_{L_0}^{\infty} \frac{L^{d-1} dL}{L^{2(d-1)(N-1)}} \sim \int_{L_0}^{\infty} \frac{dL}{L^{(d-1)(2N-3)}}$$

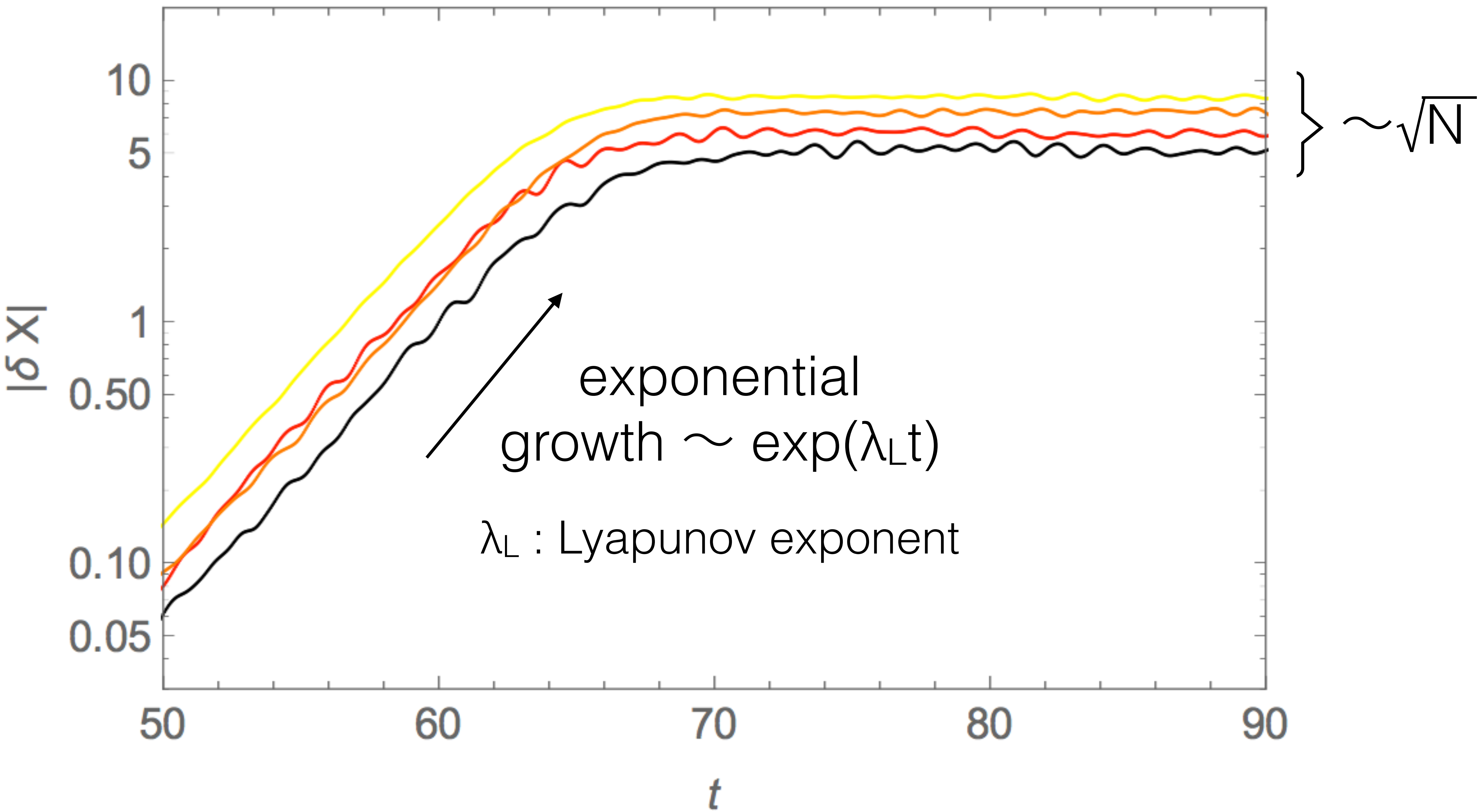
Finite! (exception: *d*=2, *N*=2)

Lyapunov Exponent



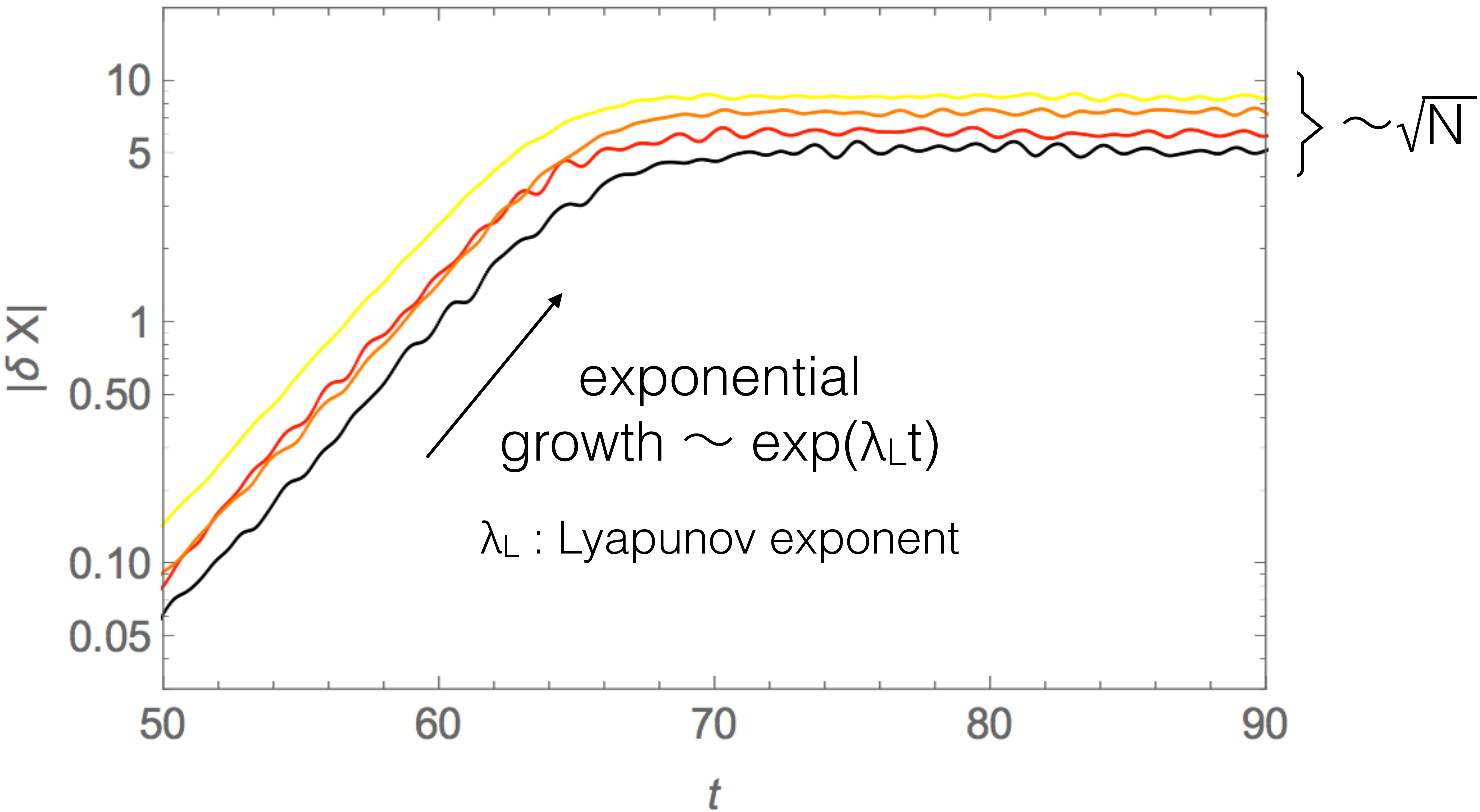

uncertainty grows
exponentially
smallest size of
the wave packet
in phase space
$\sim \hbar \sim N^0$
maximum uncertainty
$\sim$ size of the system
$\sim \sqrt{N}$

Gur-Ari, M.H., Shenker, JHEP 2016



N=6,8,12,16

Gur-Ari, M.H., Shenker, JHEP 2016

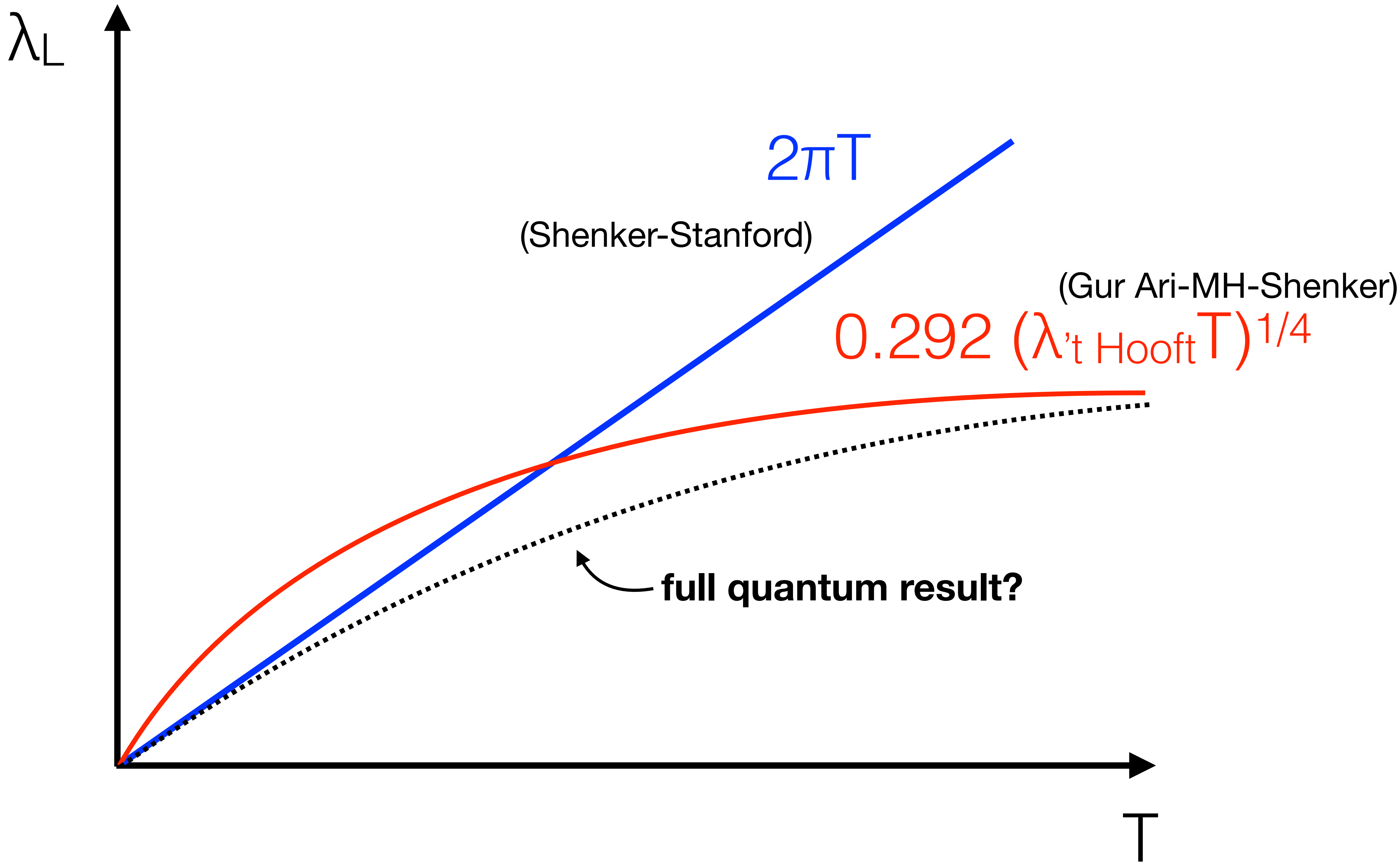


$\exp(\lambda_L t_s) \sim \sqrt{N}$

→ "scrambling time" $t_s = (\log N)/\lambda_L \sim \log N$

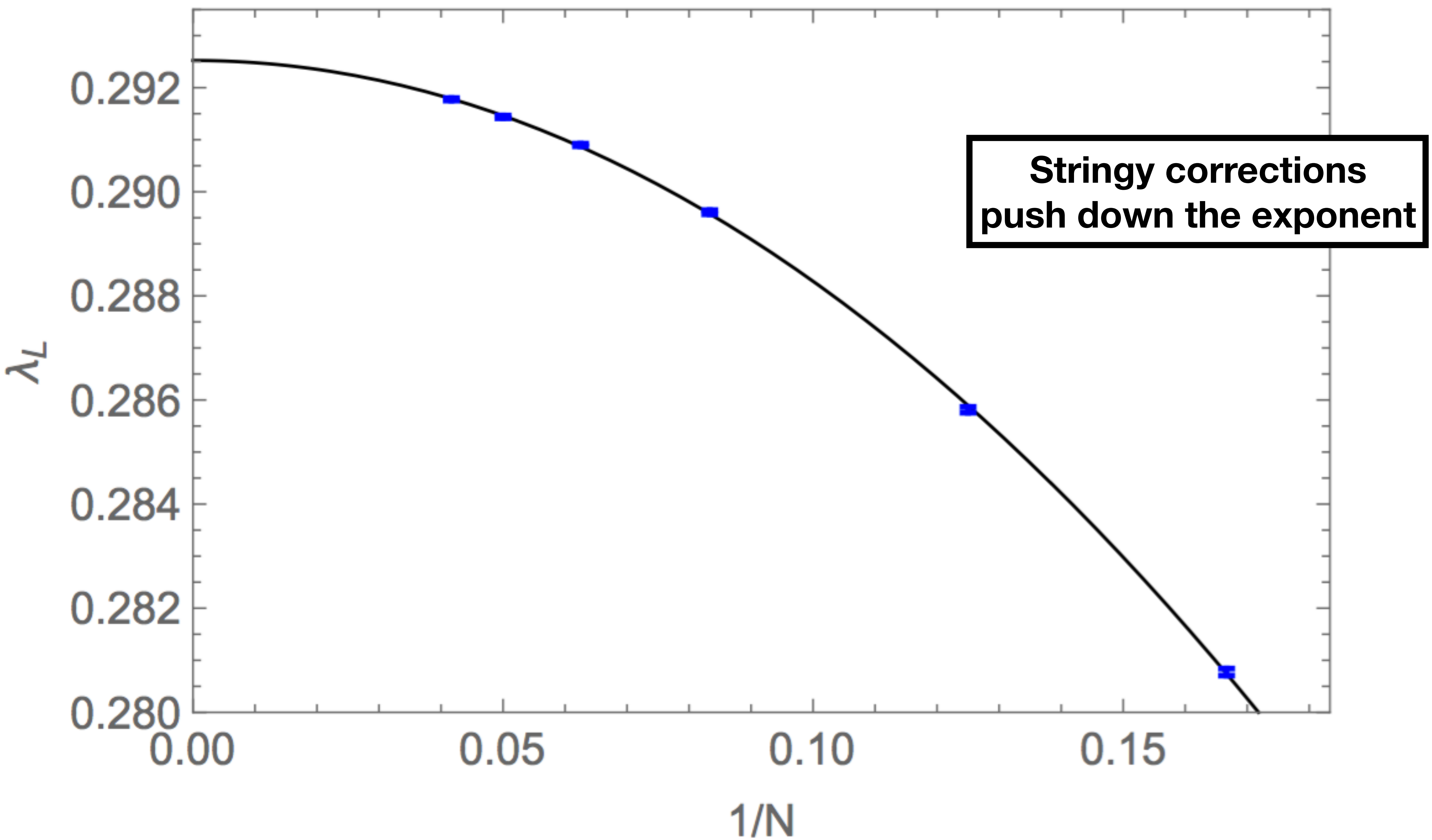
Lyapunov exponent @ large N

(D1 and D2 are similar)

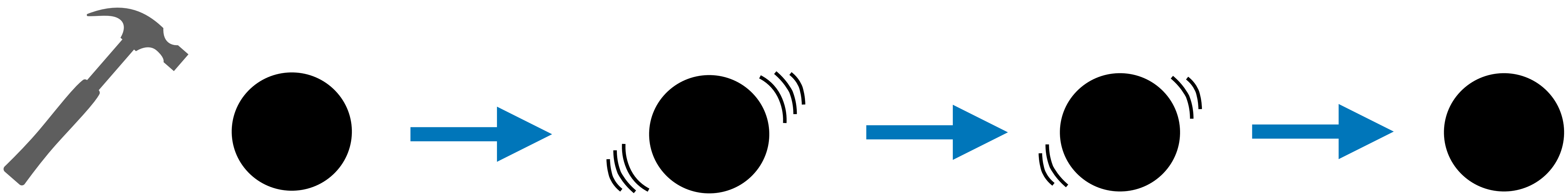


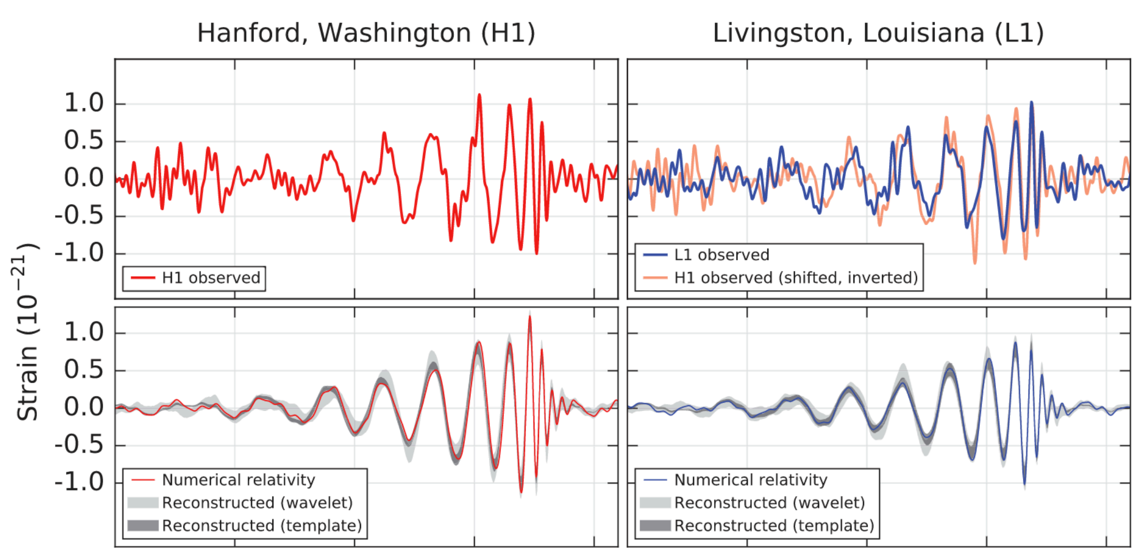
1/N correction

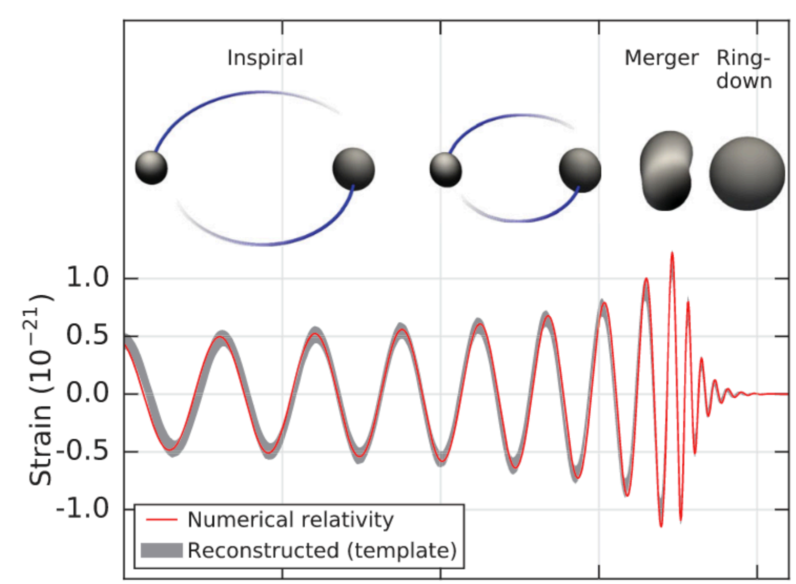
(Gur Ari-MH-Shenker)



Quasinormal mode





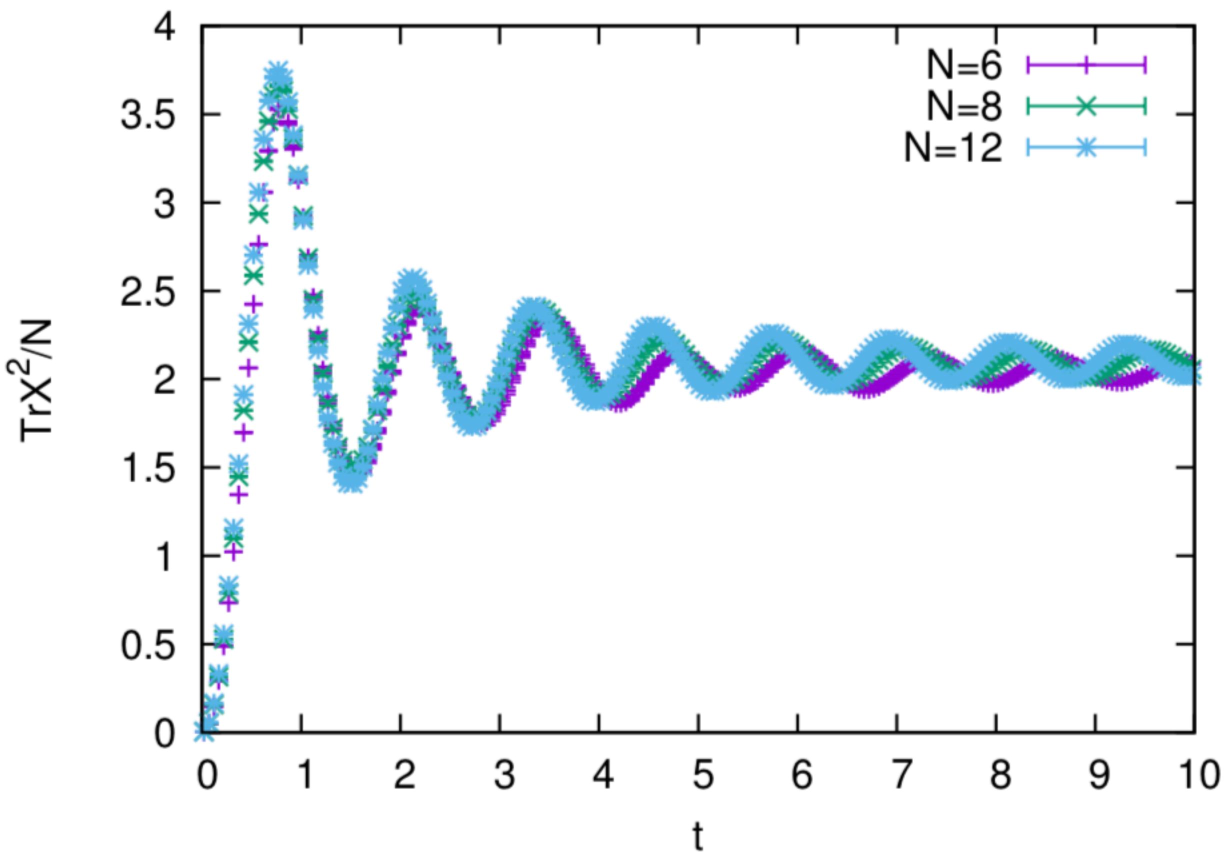


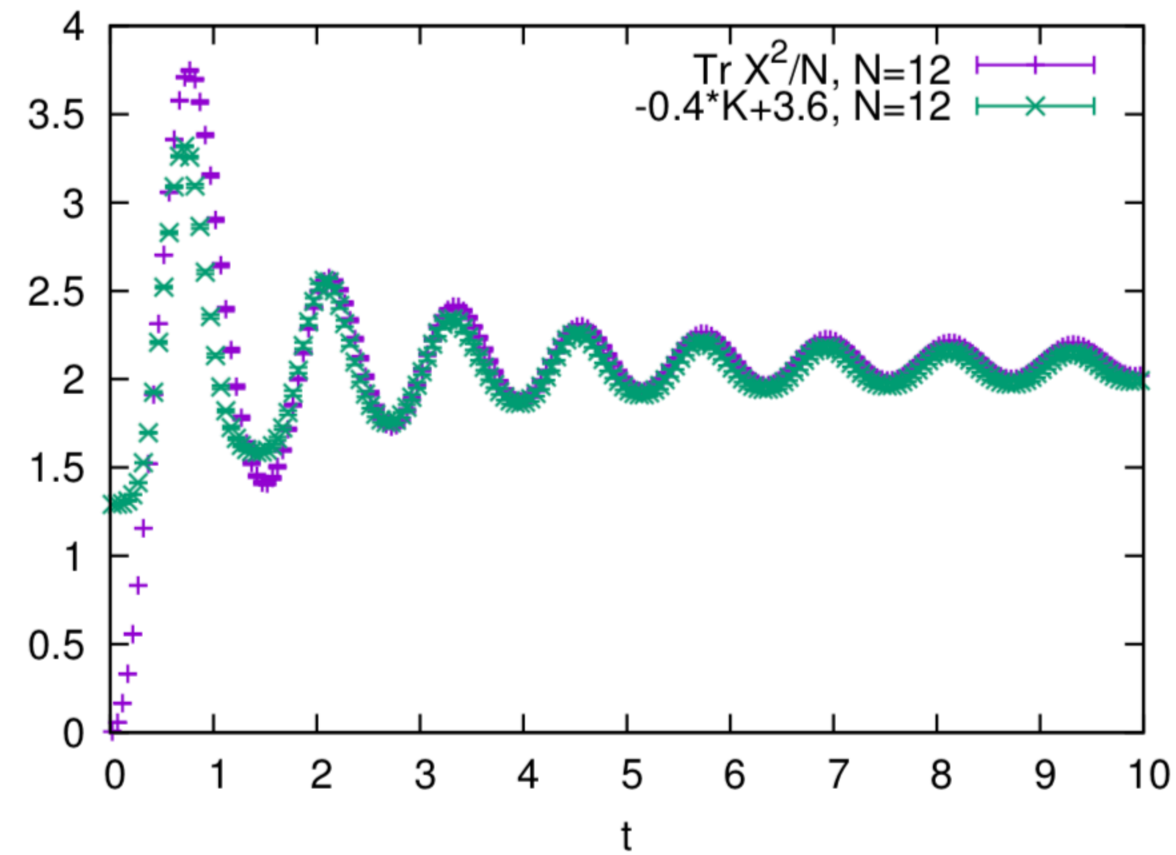
(LIGO Scientific Collaboration and Virgo Collaboration, 2016)

Quasinormal mode

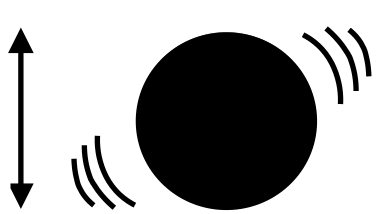
Aoki-MH-Iizuka
MH-Romatschke

$$X_M = 0, \dot{X}_M \neq 0 \xrightarrow{\text{thermalize}} \text{generic configuration}$$



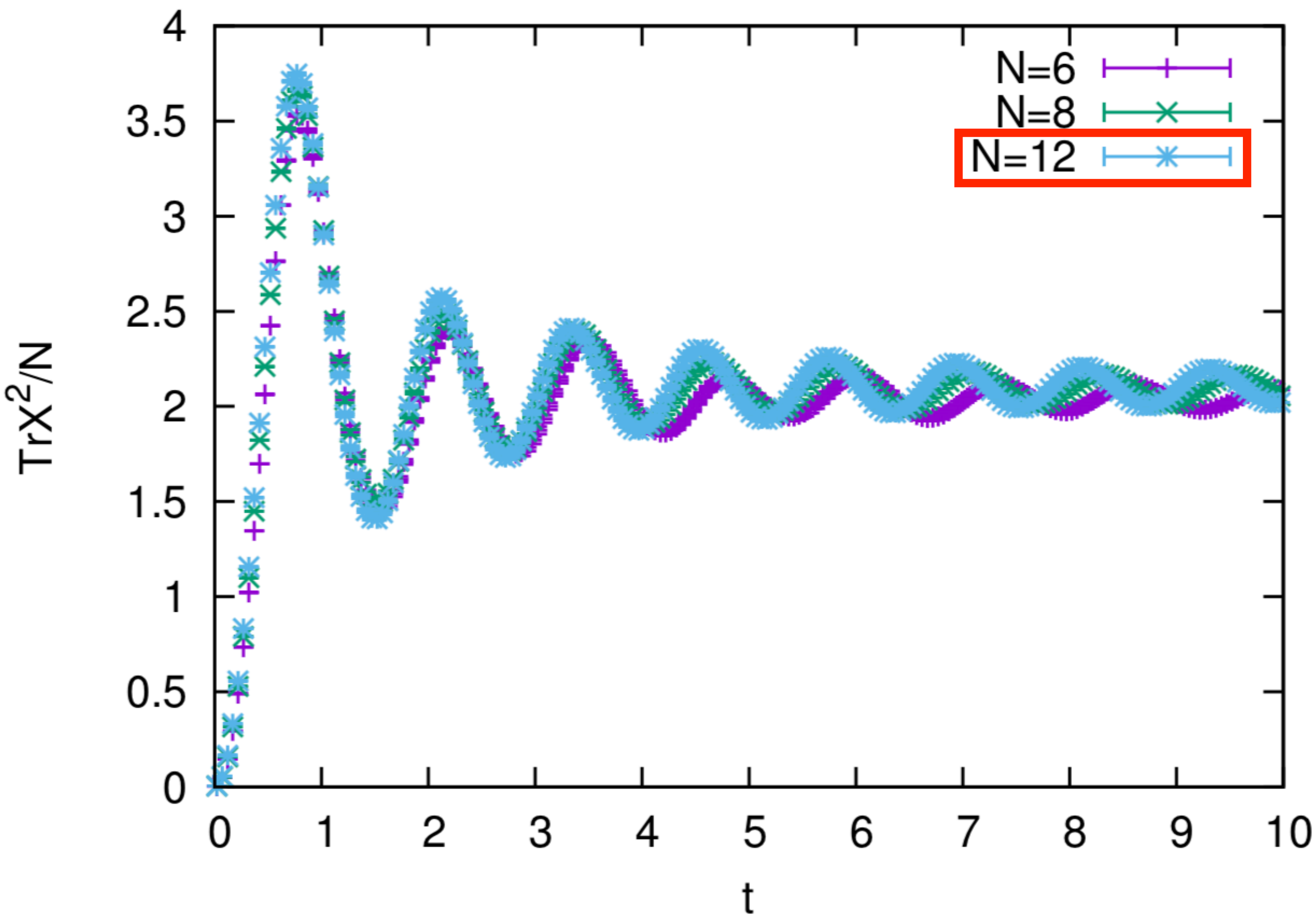


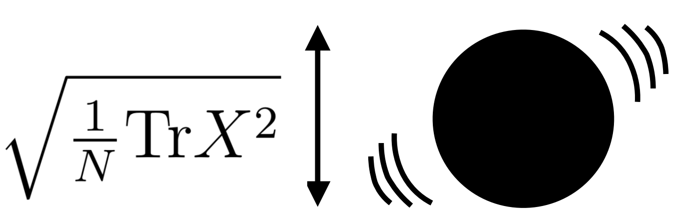
$\sqrt{\frac{1}{N}\mathrm{Tr}X^2}$



$$\mathrm{Re}(e^{i\nu t}) \sim \cos(\nu_R t) e^{-\nu_I t}$$

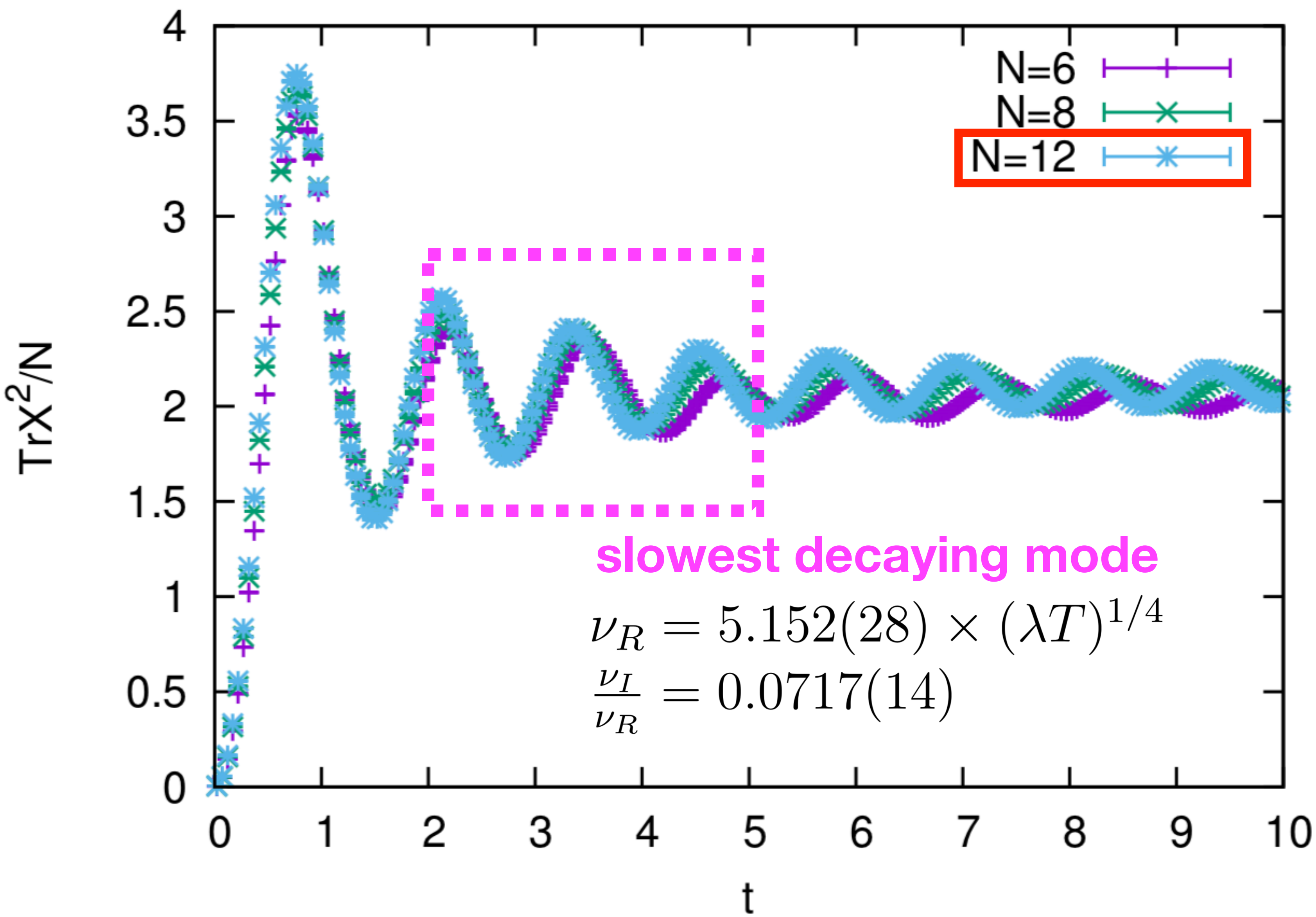
$$\mathrm{Re}(e^{i\nu t}) \sim \cos(\nu_R t) e^{-\nu_I t}$$



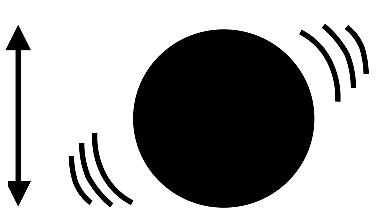


MH-Romatschke

$$\mathrm{Re}(e^{i\nu t}) \sim \cos(\nu_R t) e^{-\nu_I t}$$

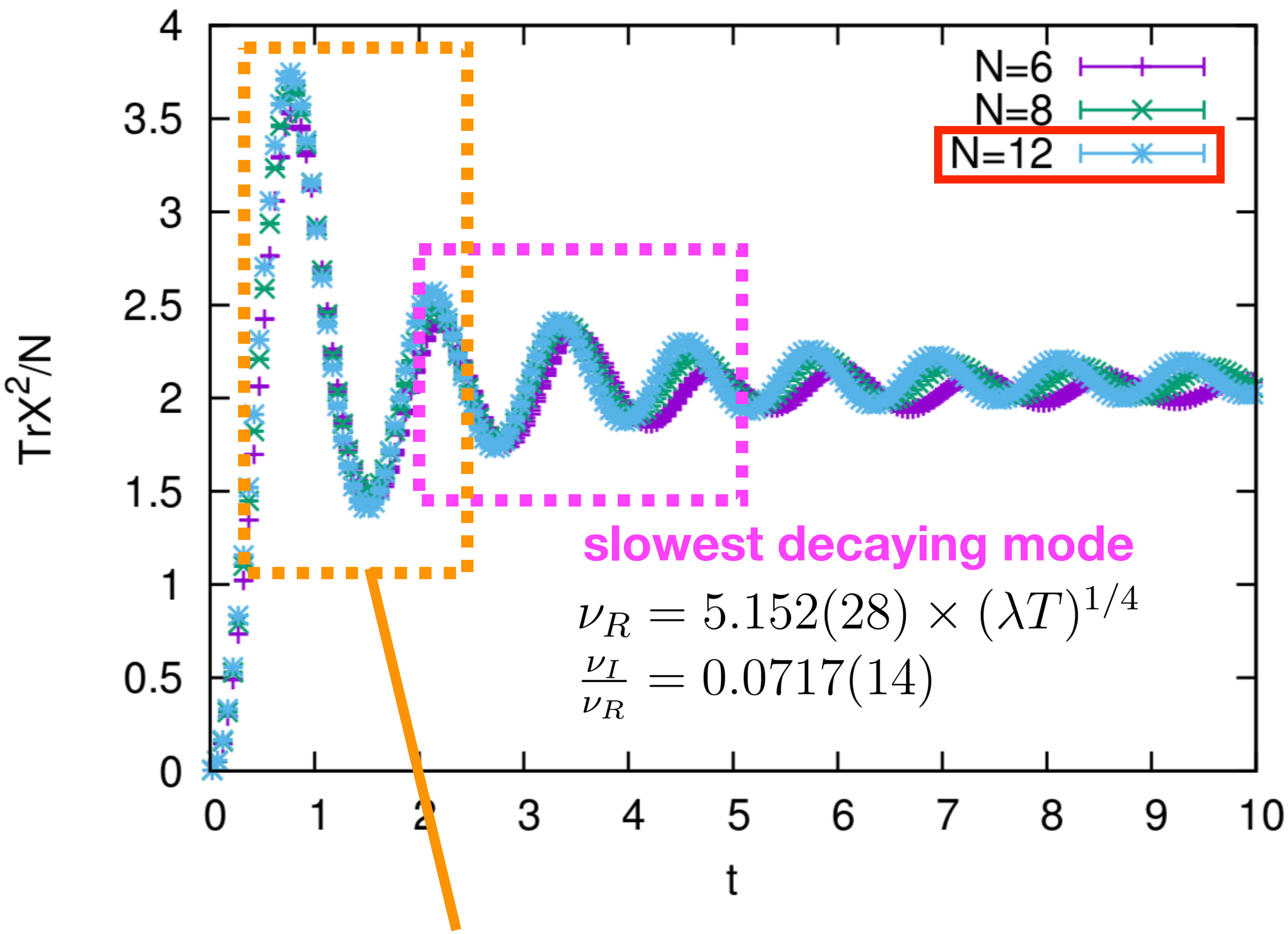


$\sqrt{\frac{1}{N}\mathrm{Tr}X^2}$



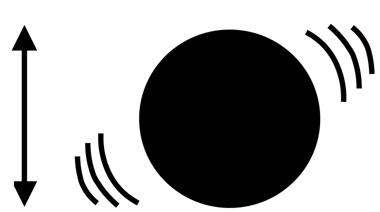
MH-Romatschke

$$\mathrm{Re}(e^{i\nu t}) \sim \cos(\nu_R t)e^{-\nu_I t}$$



'contaminated' by fast decaying modes

$\sqrt{\frac{1}{N}\mathrm{Tr}X^2}$

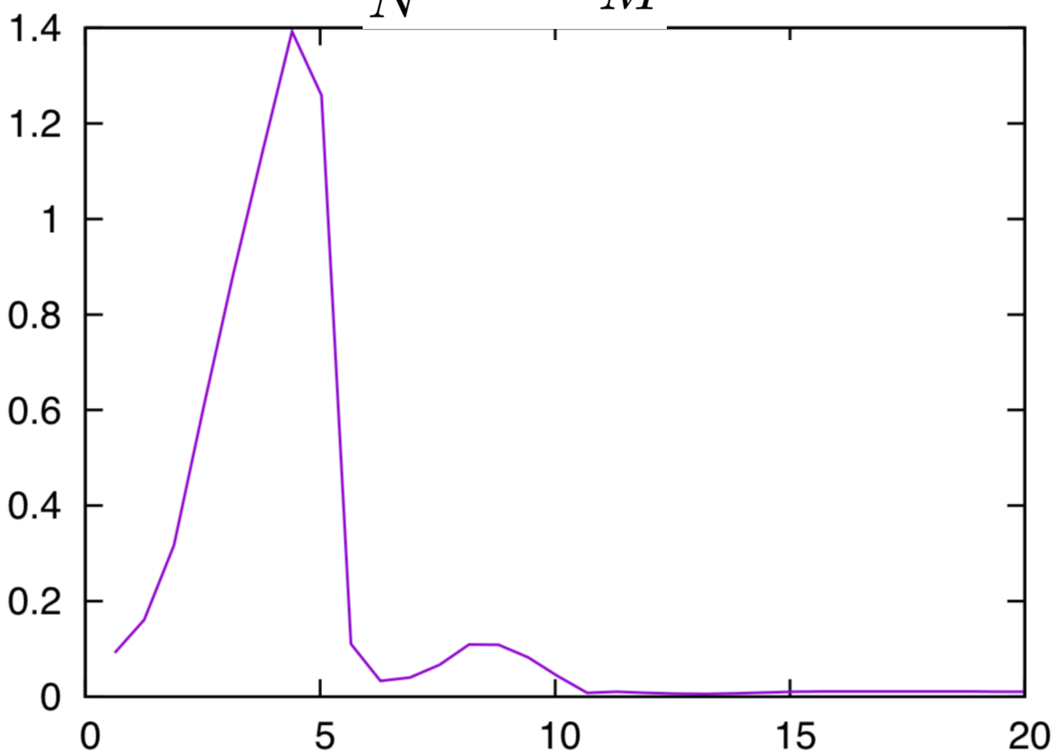


$$\nu_R = 4.63(22) \times (\lambda T)^{1/4}$$
$$\frac{\nu_I}{\nu_R} = 0.183(33)$$

MH-Romatschke

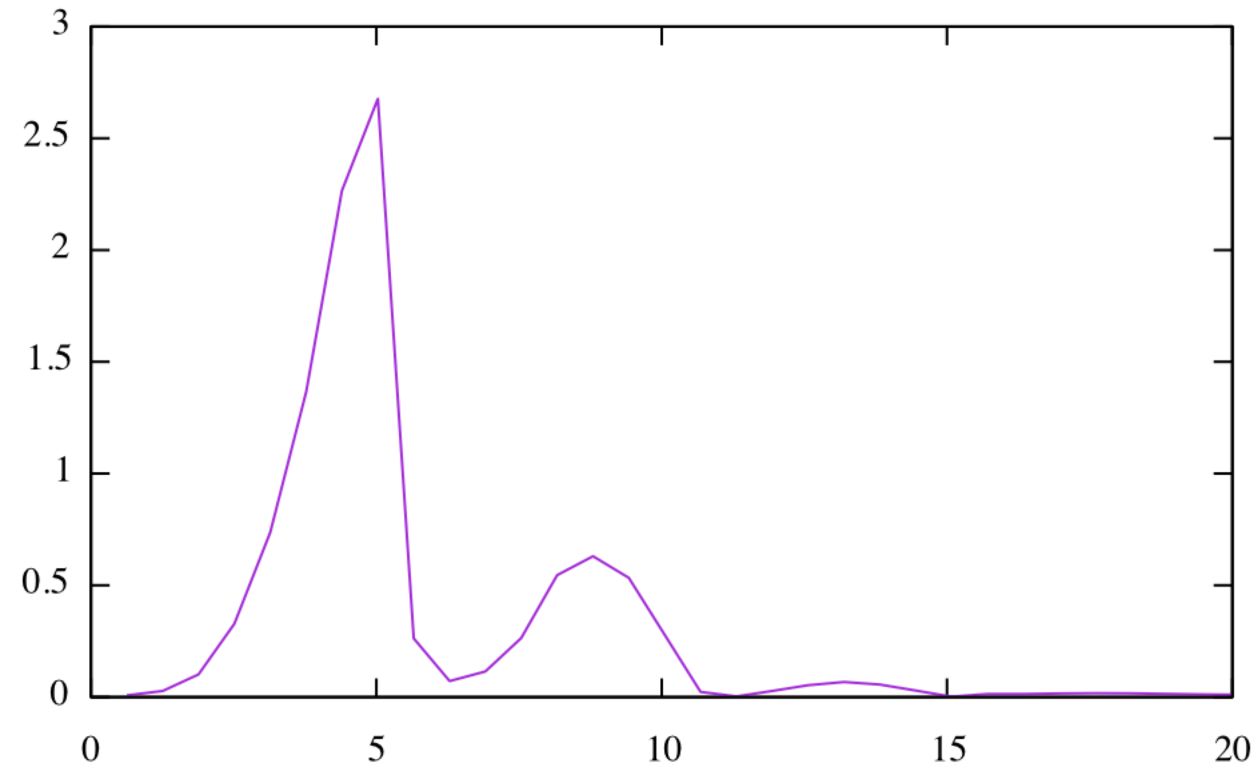
Fourier modes

$\frac{1}{N}\mathrm{Tr}X_M^2$



ν_R

kinetic energy

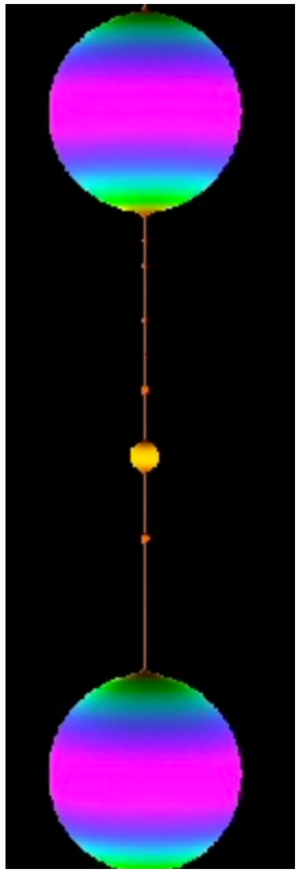


ν_R

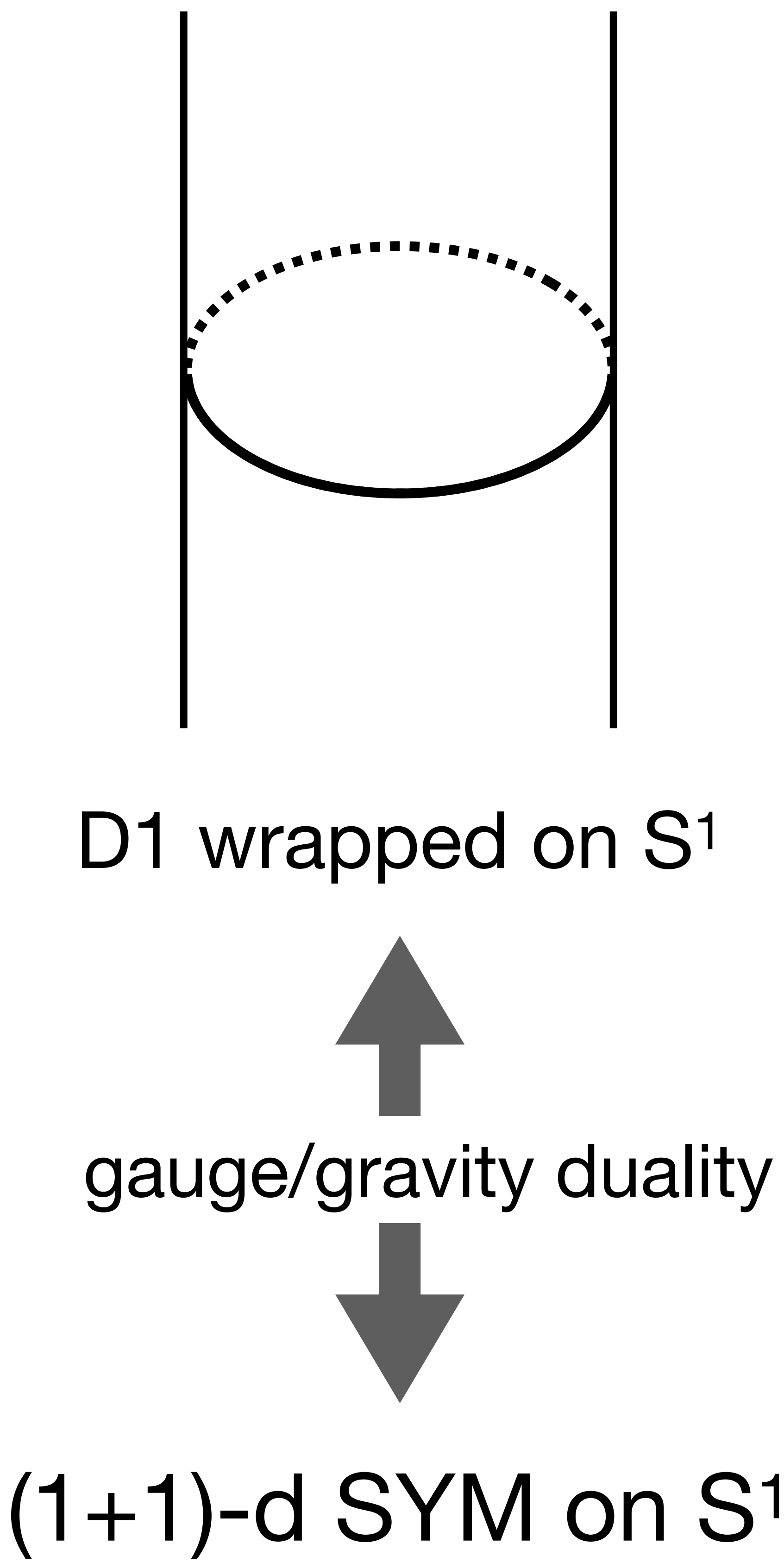
MH-Romatschke

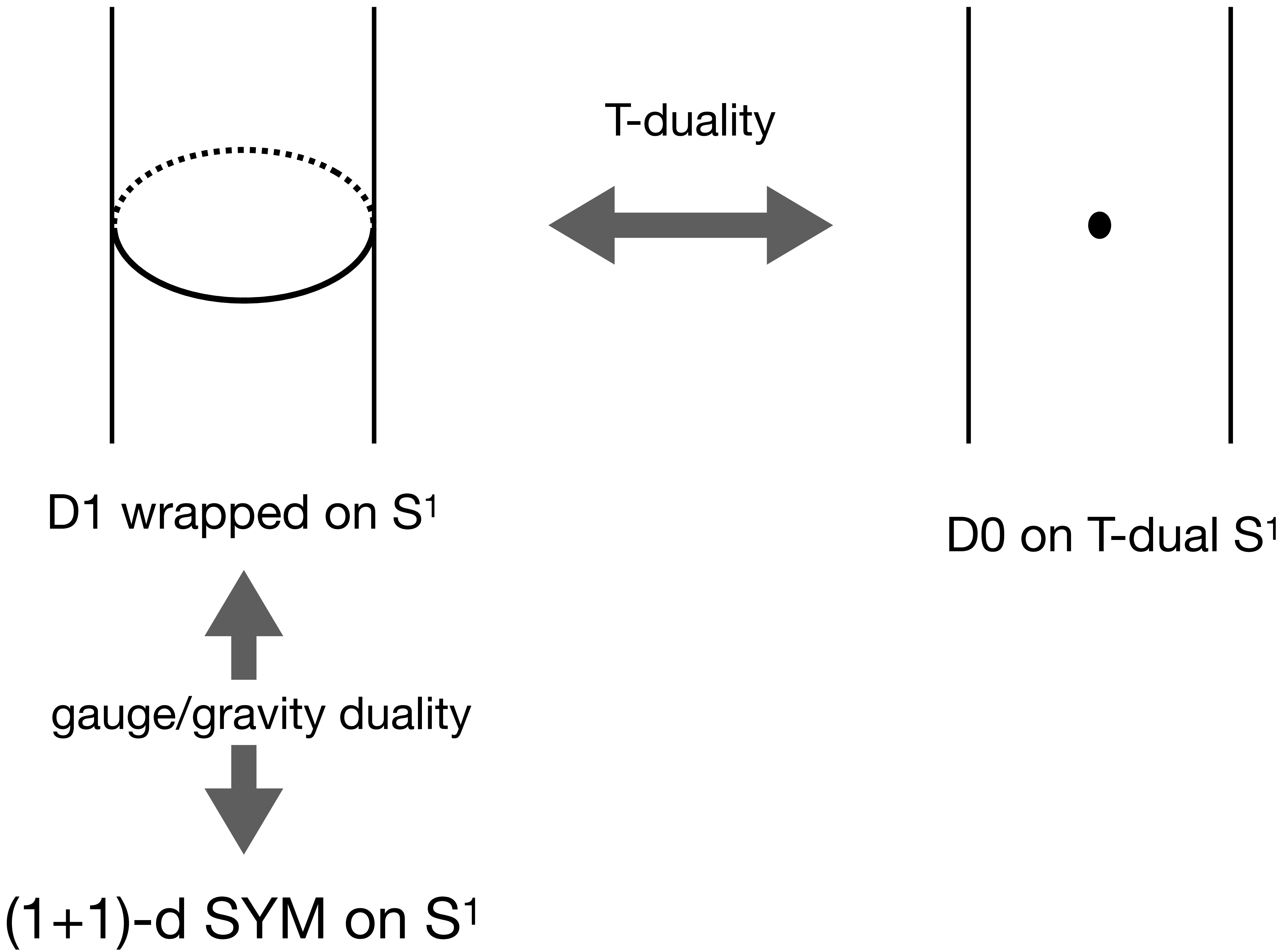
Black hole/black string topology change

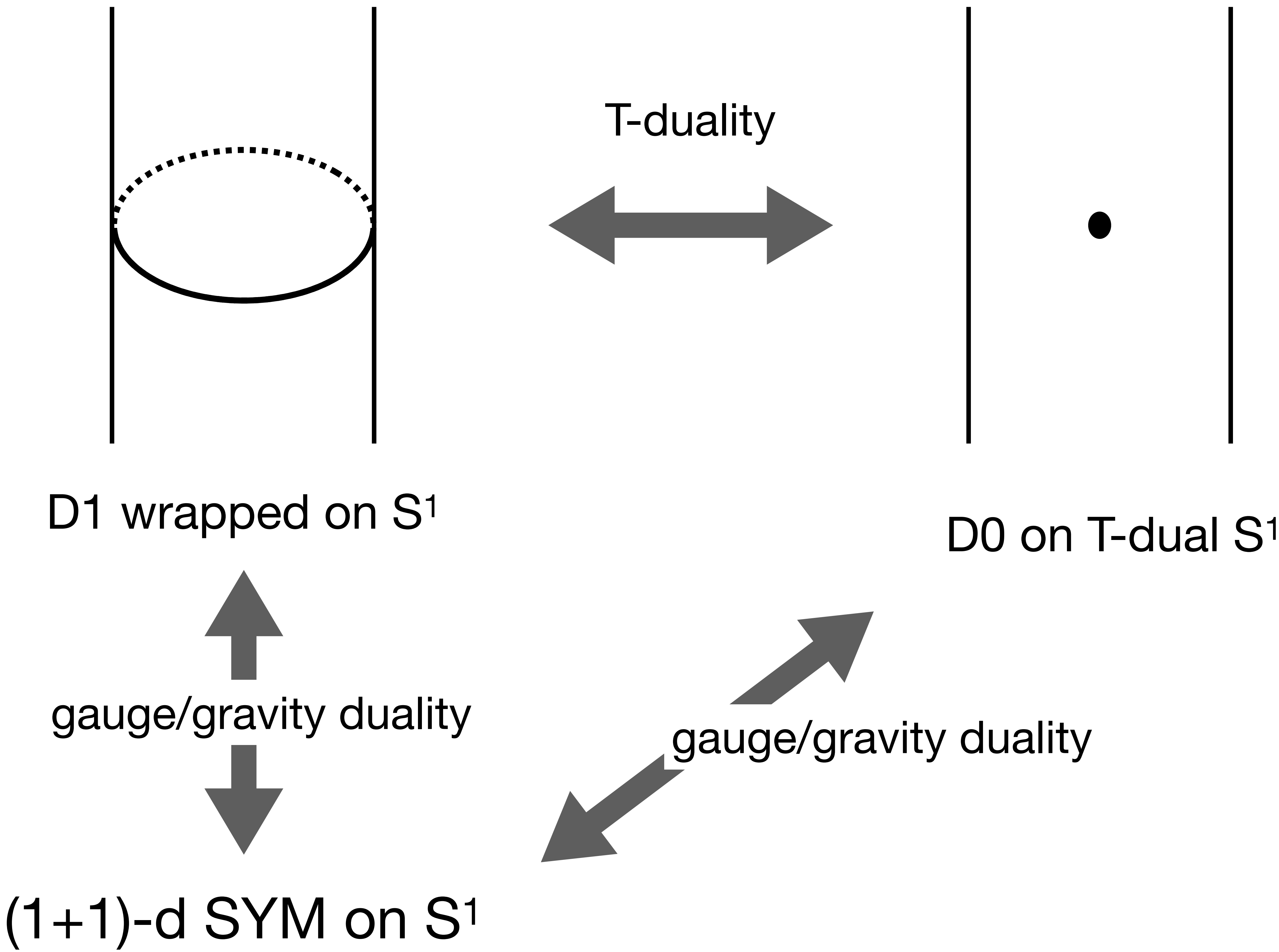
MH-Romatschke



(From F. Pretorius's webpage)


D1 wrapped on S1
gauge/gravity duality
(1+1)-d SYM on S1

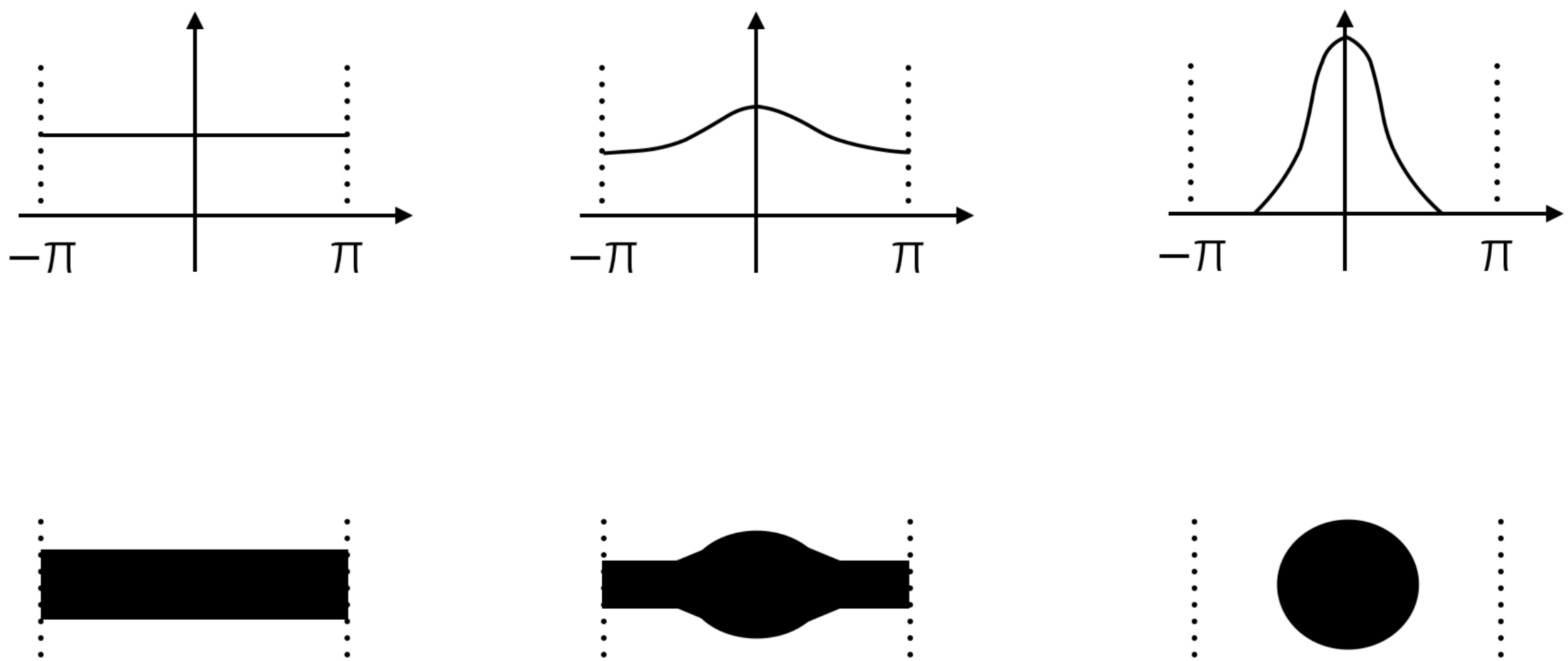

T-duality
D1 wrapped on S^1
D0 on T-dual S^1
gauge/gravity duality
(1+1)-d SYM on S^1



T-duality
D1 wrapped on S¹
D0 on T-dual S¹
gauge/gravity duality
gauge/gravity duality
(1+1)-d SYM on S¹

Wilson line phase = location of D0

Distribution of Wilson line phase

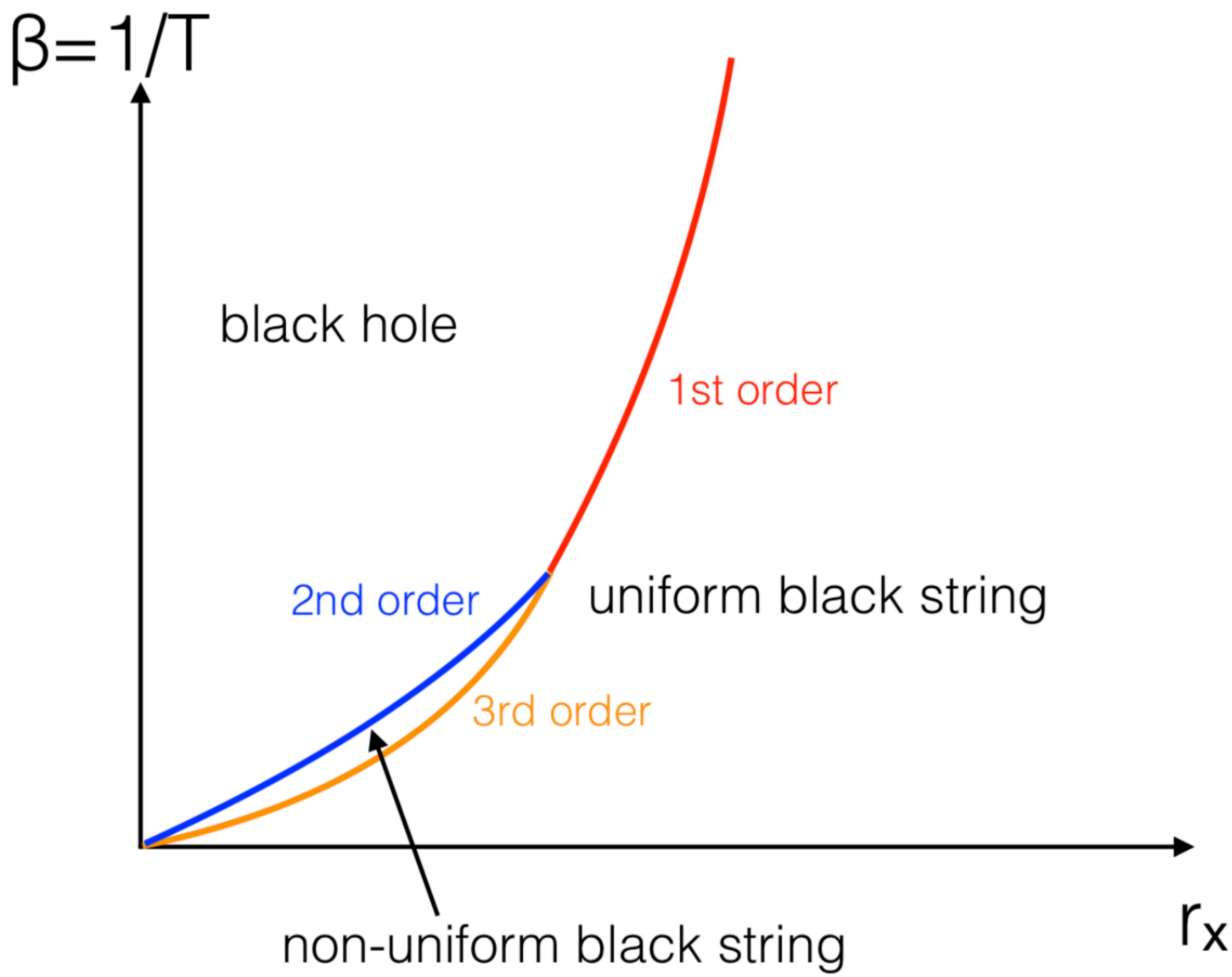


uniform string **nonuniform string** **black hole**

(e.g. Aharony-Marsano-Minwalla-Wiseman)

Conjectured phase diagram

Aharony-Marsano-Minwalla-Wiseman,
Kawahara-Nishimura-Takeuchi,
Catterall-Joseph-Wiseman, …



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Aharony-Marsano-Minwalla-Wiseman,
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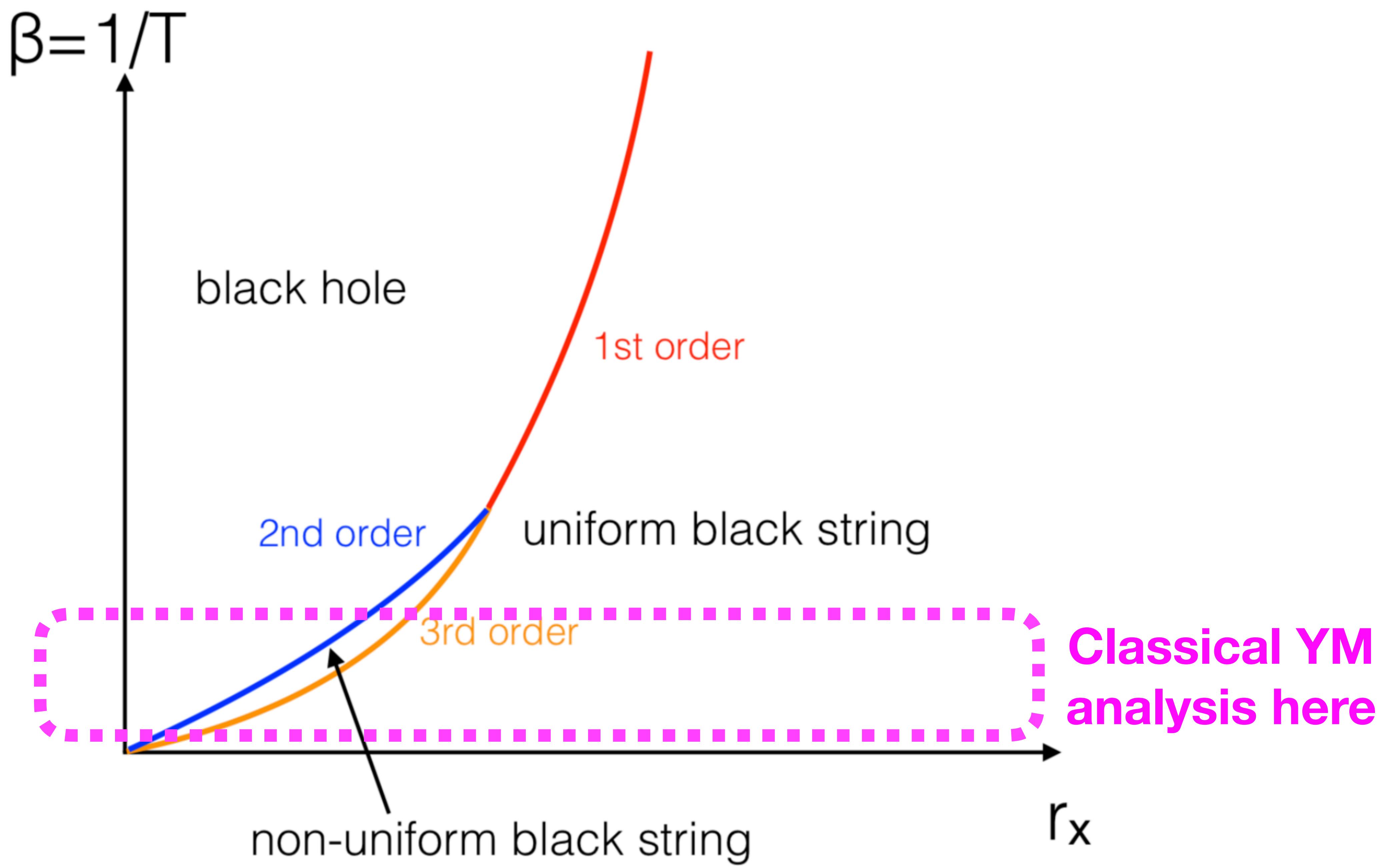
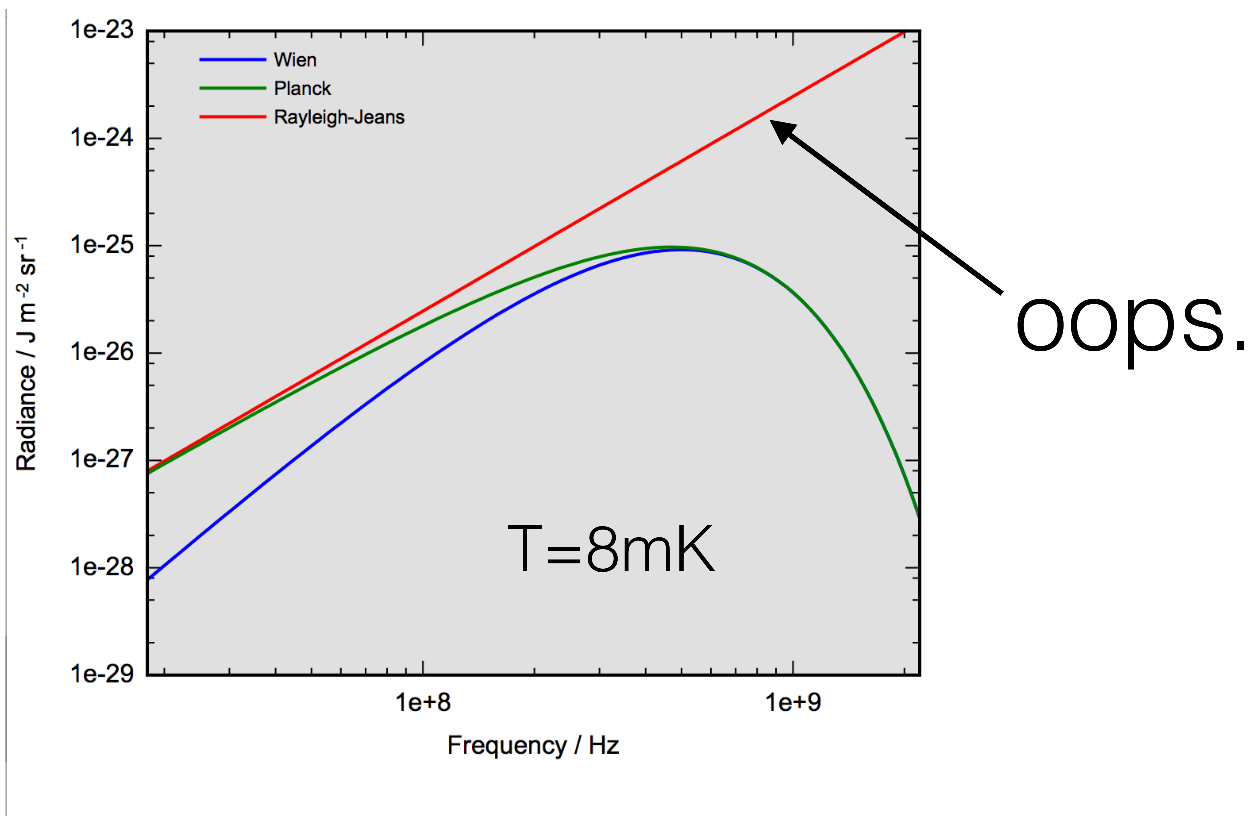
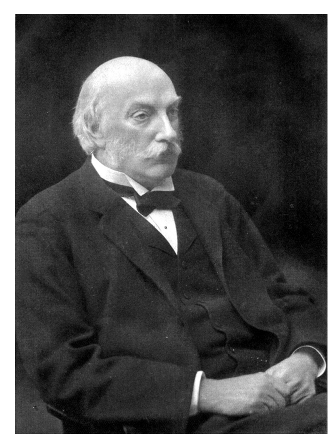


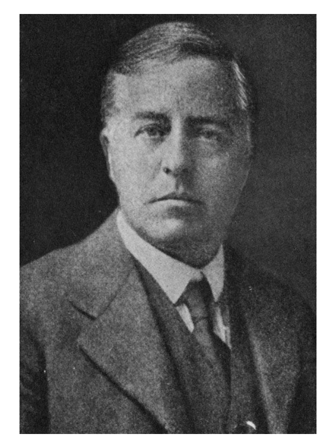
- Strictly speaking, classical YM is not well-defined — UV catastrophe problem
- It still works at early time, as long as energy localized at IR.



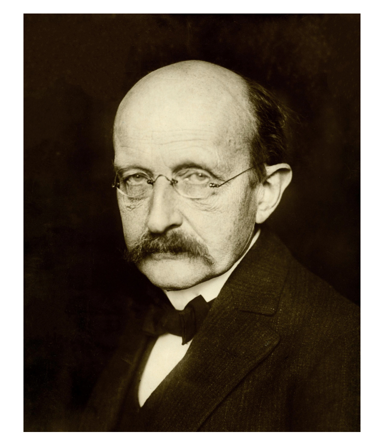
(wikipedia)



Lord Rayleigh
1842-1919

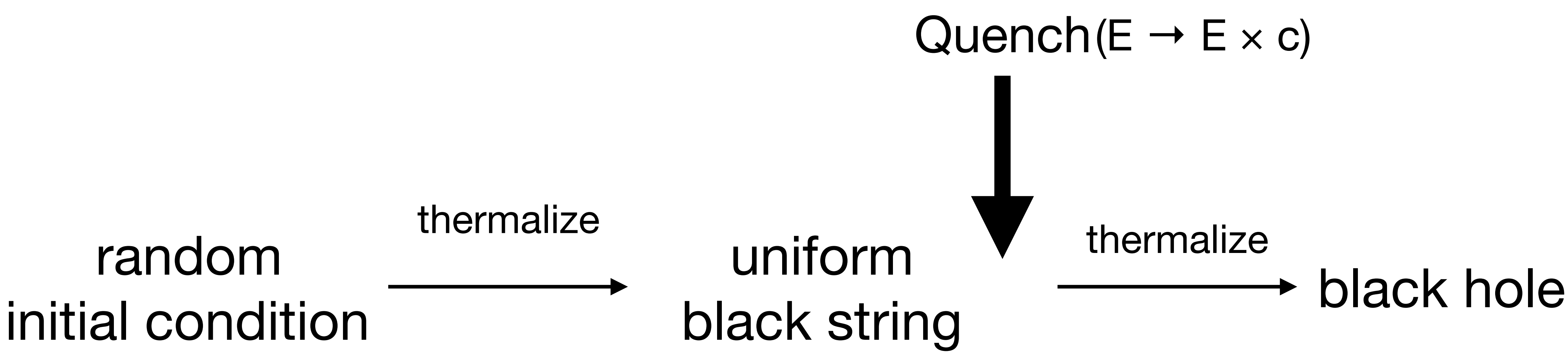


James Jeans
1877-1946



Max Planck
1858-1947

Black String →Black Hole Topology Change



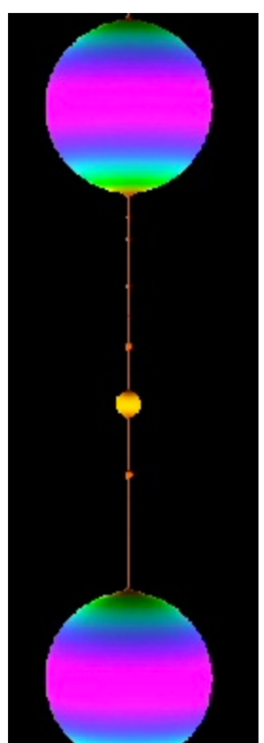
Black String → Black Hole Topology Change

Quench (E → E × c)

random initial condition —thermalize→ uniform black string —thermalize→ black hole

Topology change

GR is not enough.



(From F. Pretorius's webpage)

Black String → Black Hole Topology Change

Quench ($E \to E \times c$)

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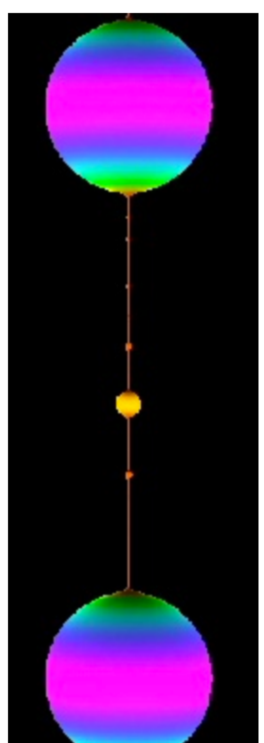
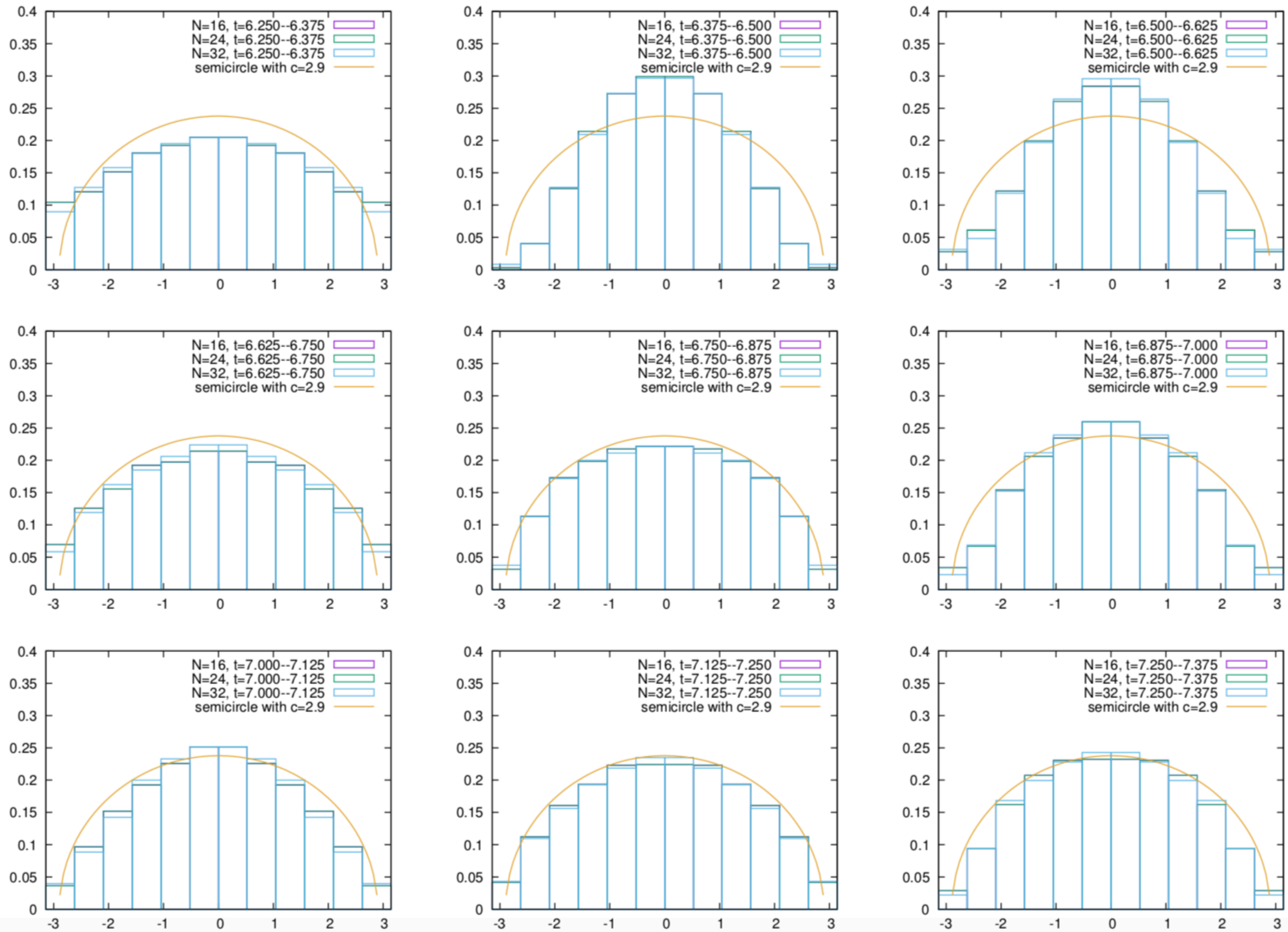


(From F. Pretorius's webpage)

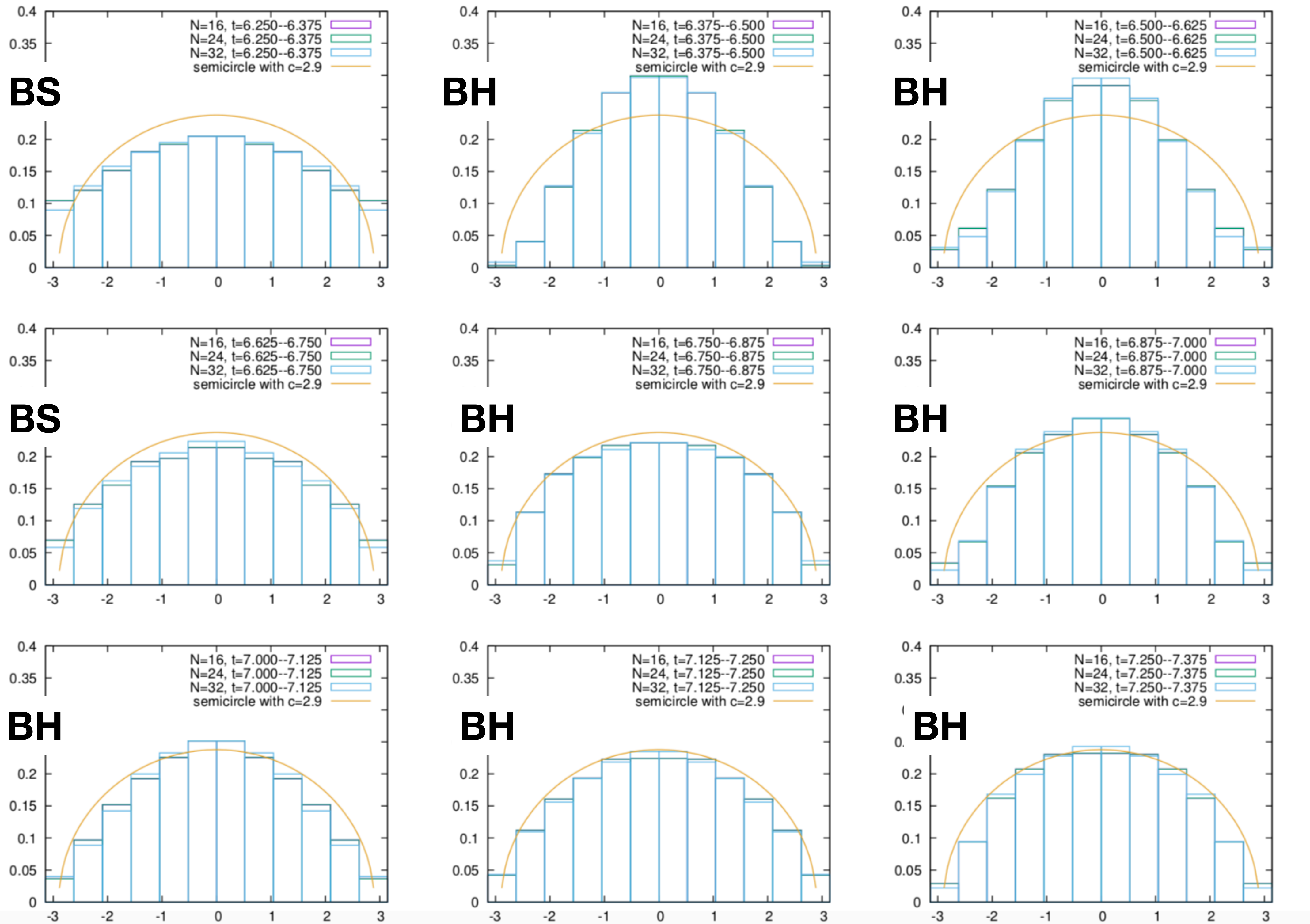
- Classical → Large α' correction
- Large N → No g_s correction

Can α' alone assist the topology change?

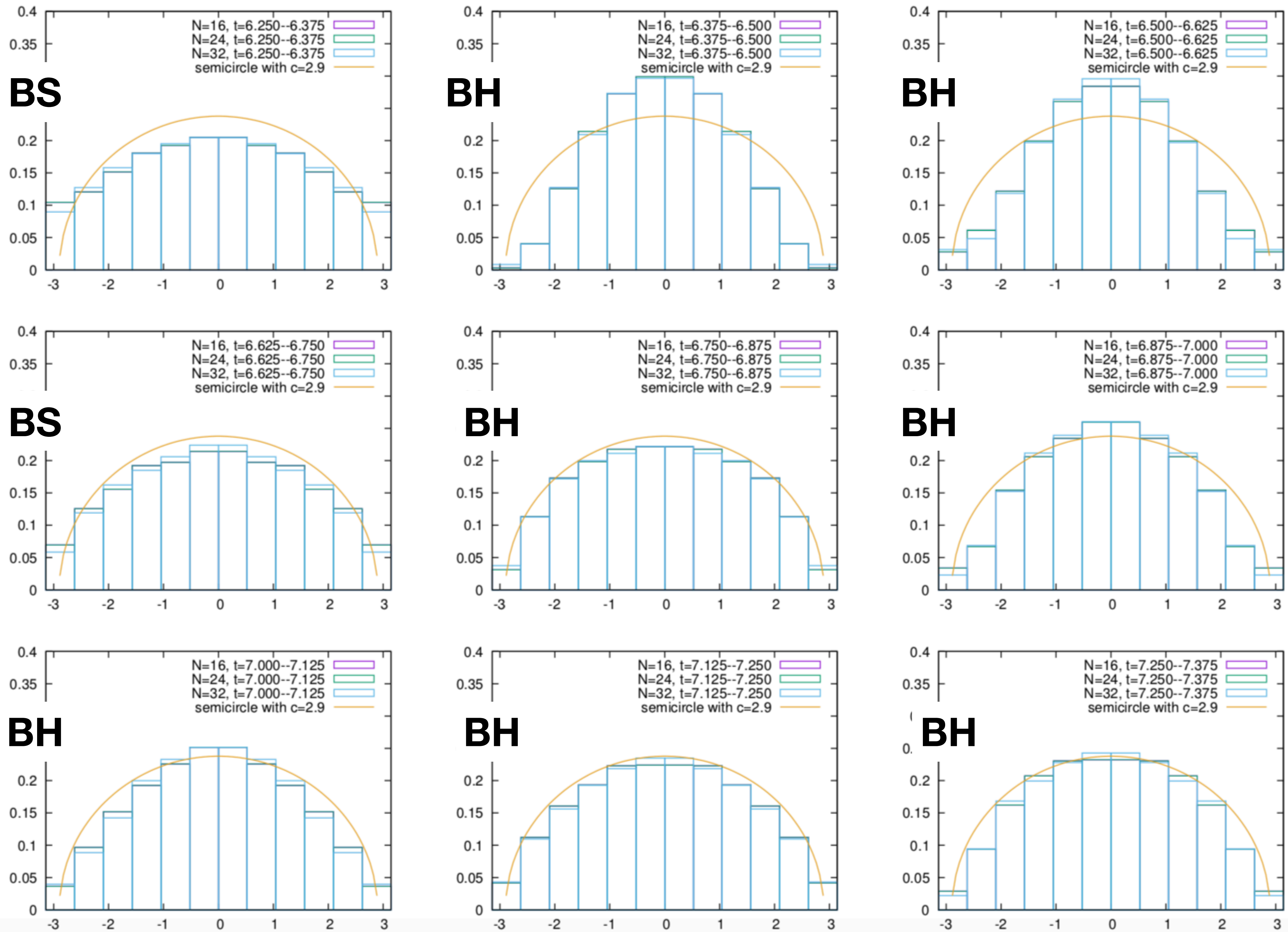
T_{BS}, T_{BH} fixed (E_{BS}/N^2, E_{BH}/N^2 fixed)



T_{BS}, T_{BH} fixed (E_{BS}/N^2, E_{BH}/N^2 fixed)

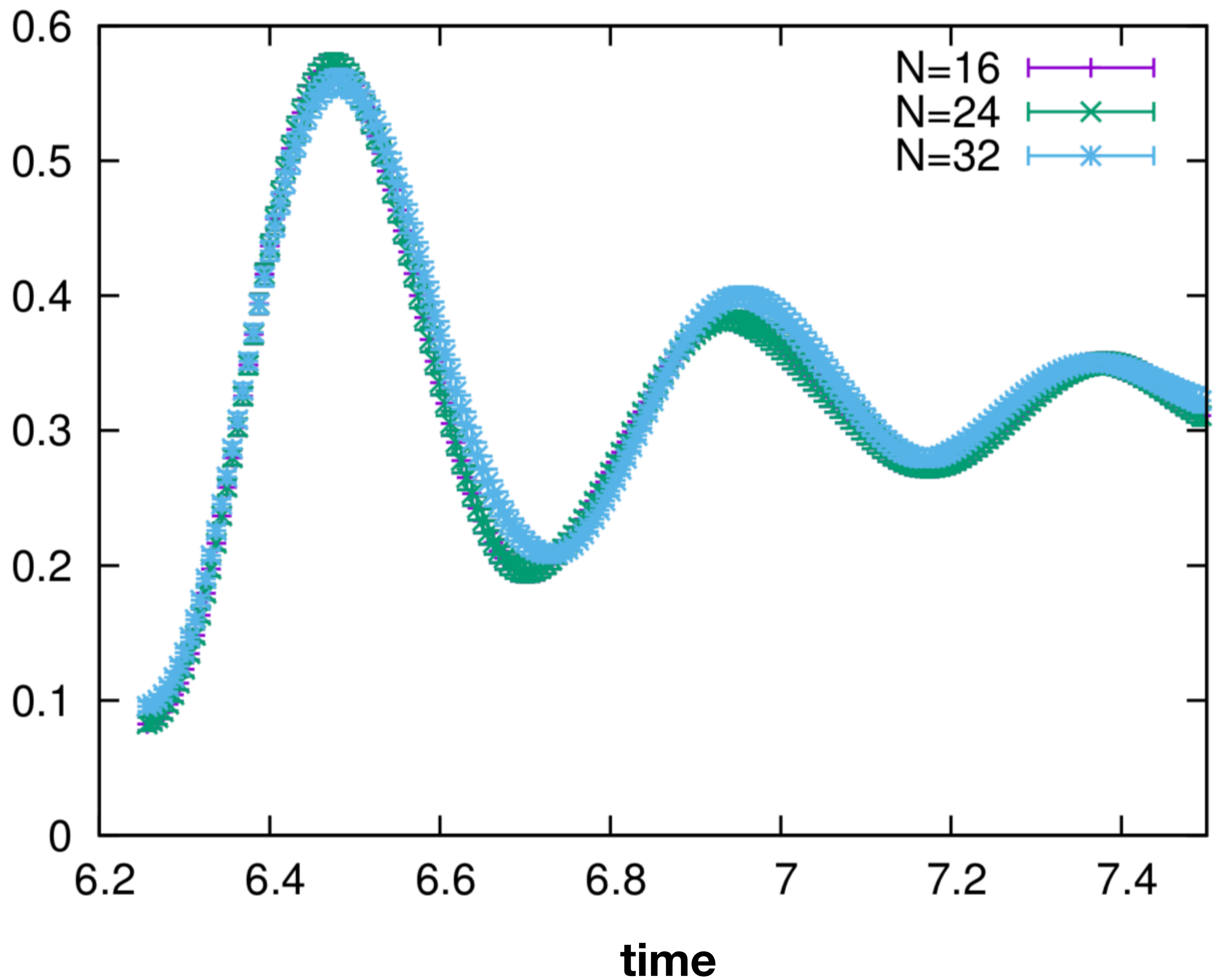


T_{BS}, T_{BH} fixed (E_{BS}/N^2,E_{BH}/N^2 fixed)

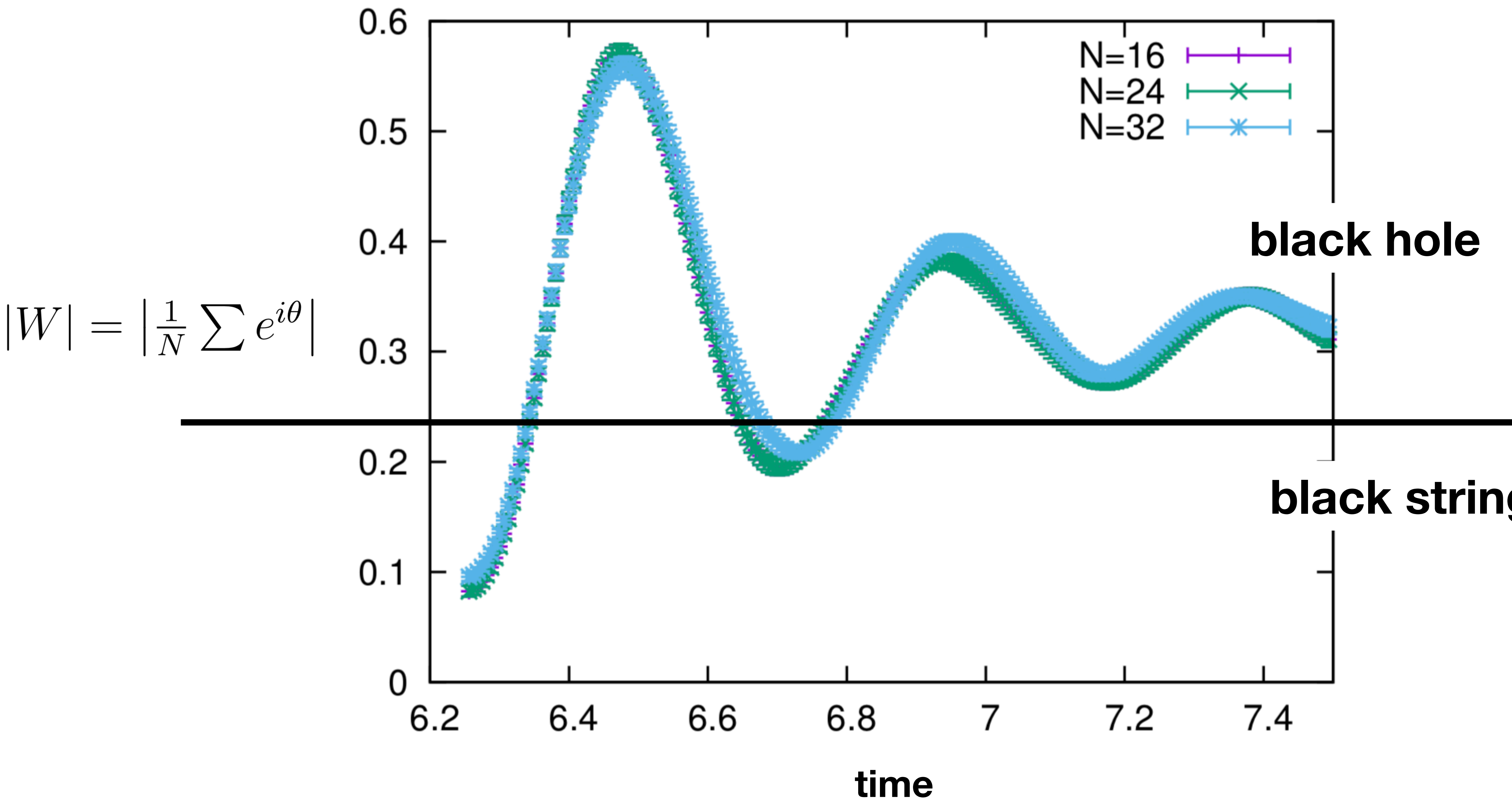


α’ correction is enough.

$|W| = \left|\frac{1}{N}\sum e^{i\theta}\right|$



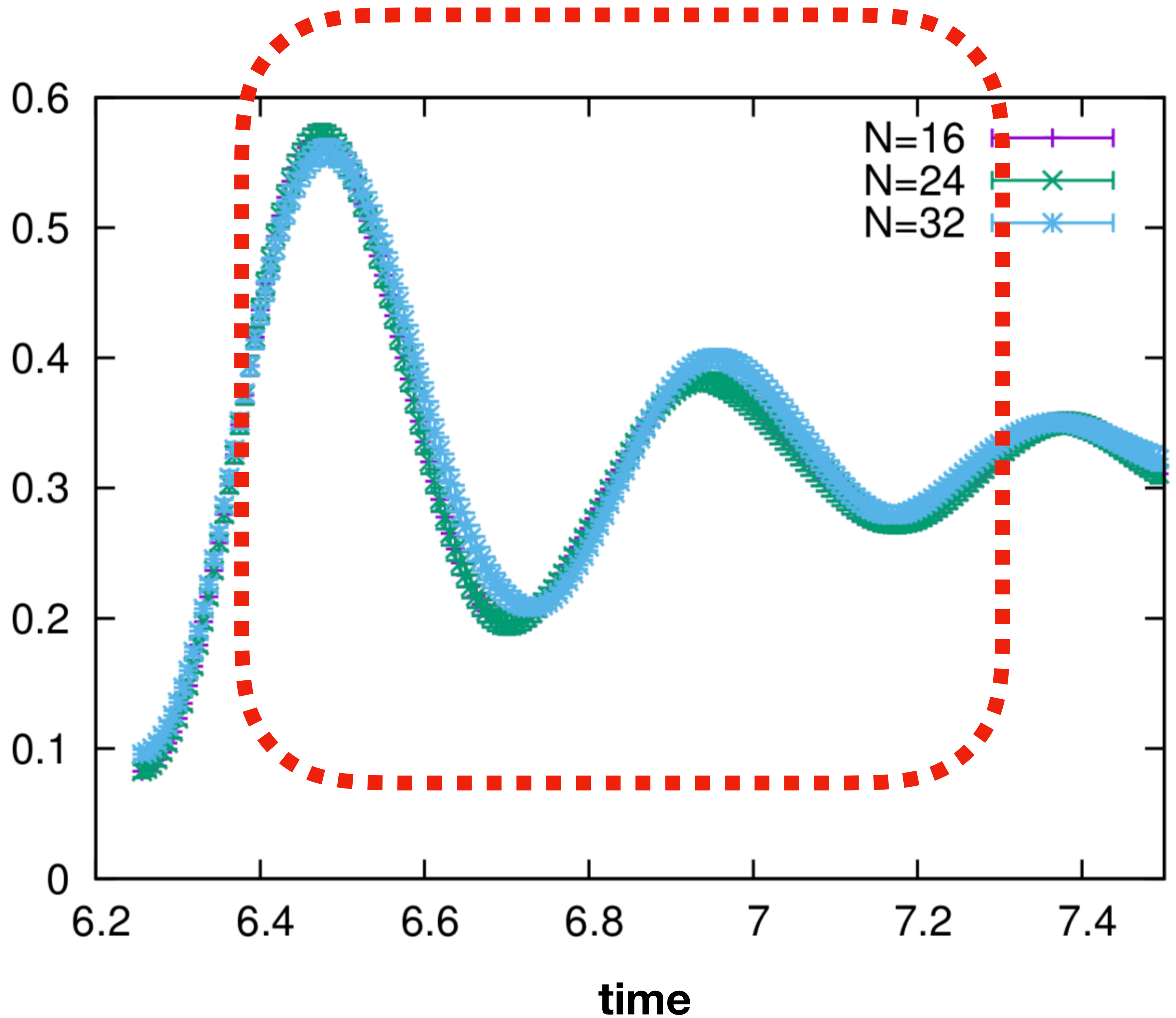
T_{BS}, T_{BH} fixed (E_{BS}/N^2,E_{BH}/N^2 fixed)



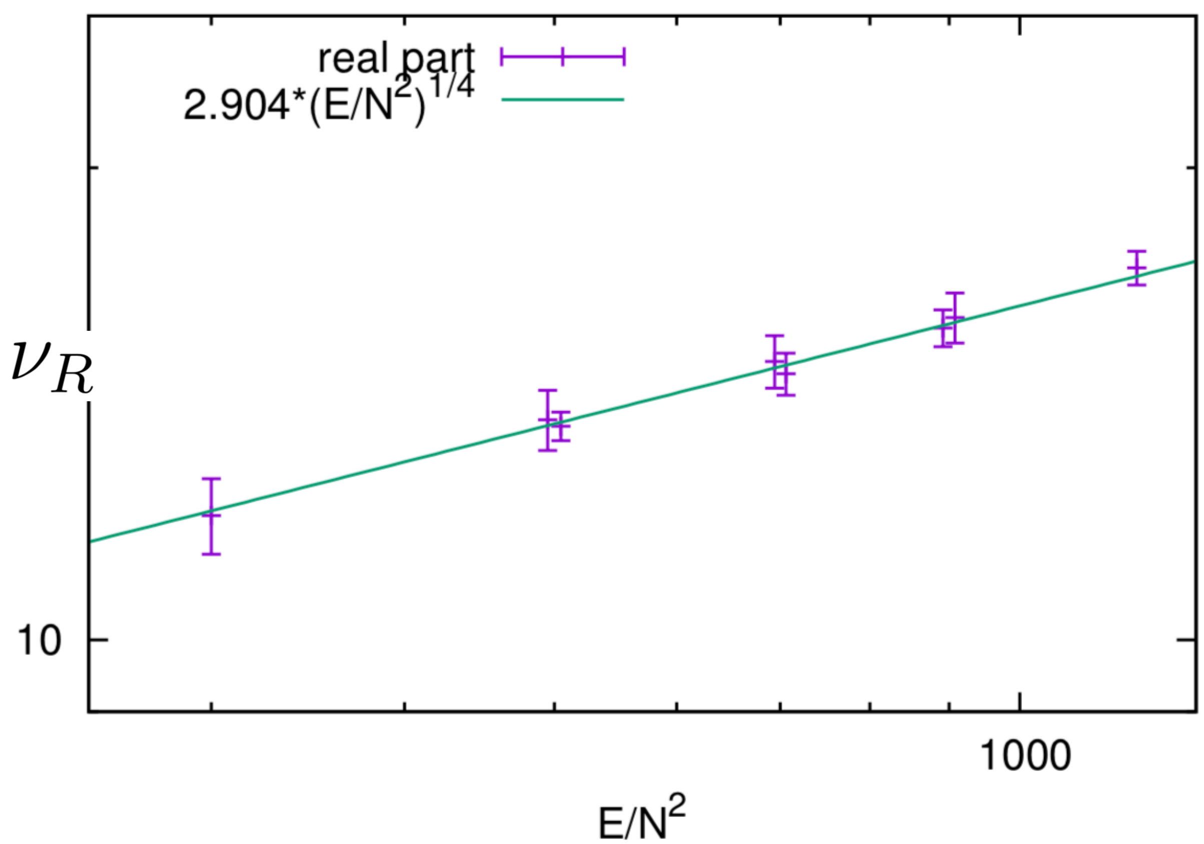
T_{BS}, T_{BH} fixed (E_{BS}/N^2,E_{BH}/N^2 fixed)

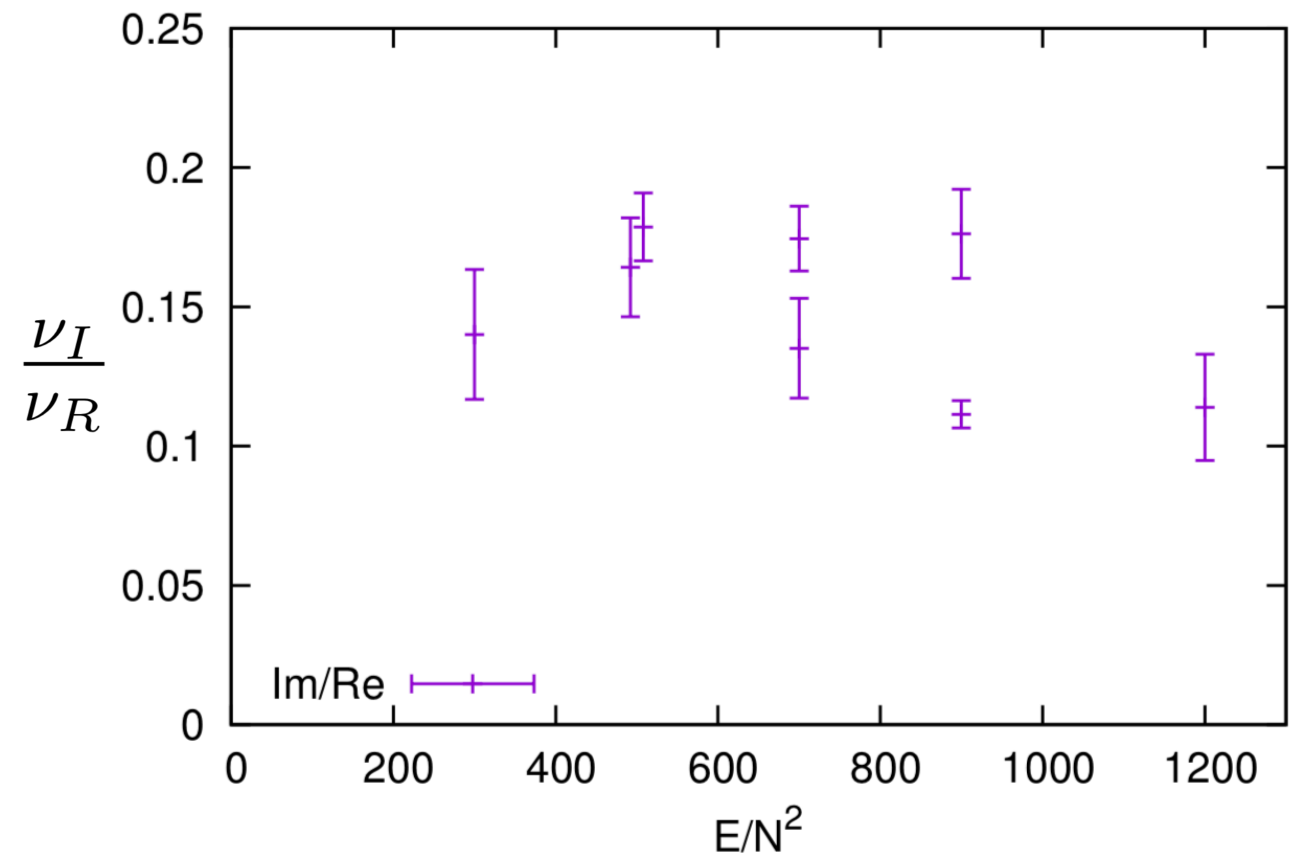
Quasinormal mode can be estimated

$$|W| = \left|\frac{1}{N}\sum e^{i\theta}\right|$$



T_{BS}, T_{BH} fixed (E_{BS}/N^2, E_{BH}/N^2 fixed)

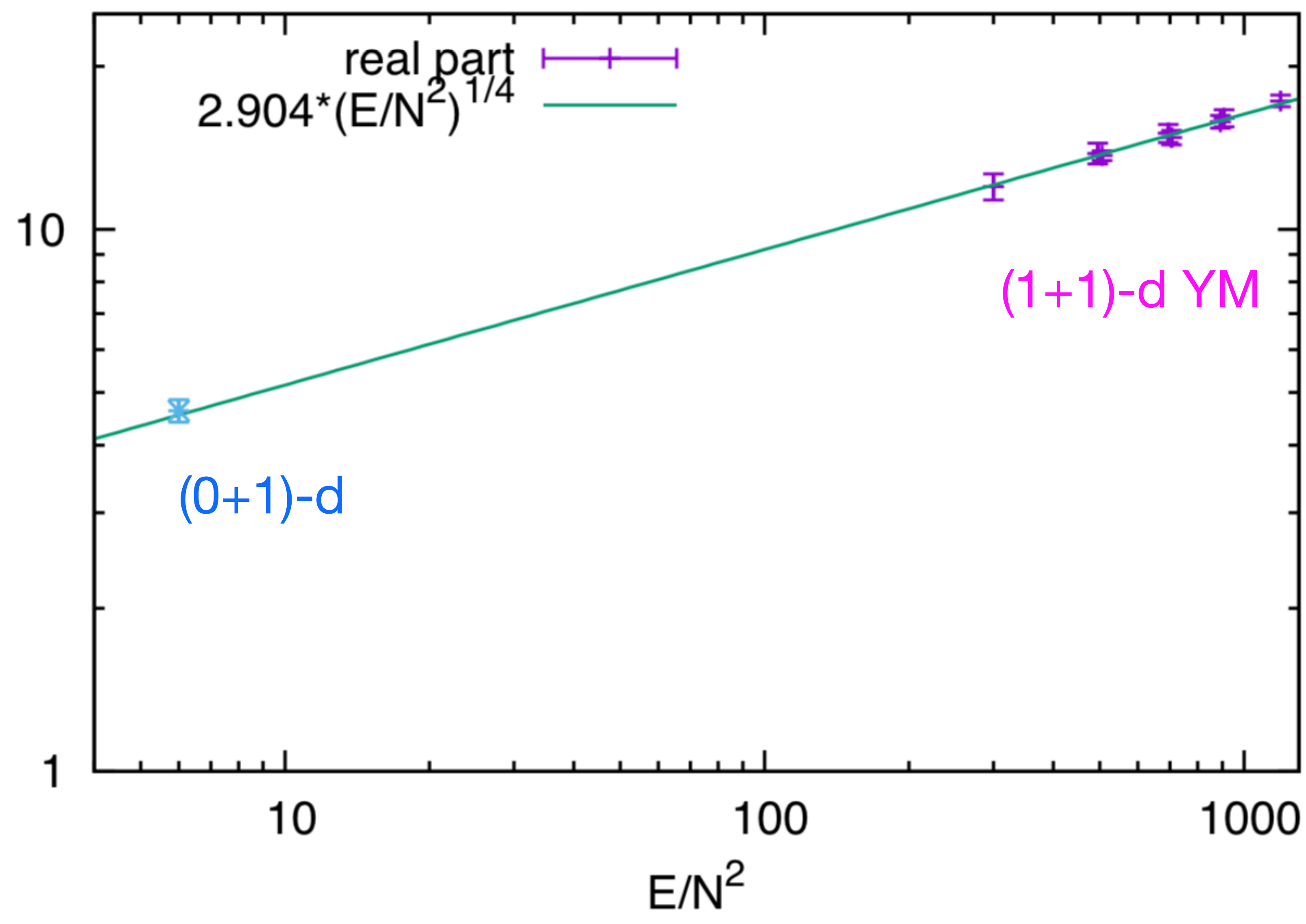




Gravity side (strong coupling in YM)

$$\nu_R \propto T,\ \frac{\nu_I}{\nu_R} = \text{const}$$ @ Uniform black string phase

(Iizuka-Kabat-Lifschytz-Lowe, 2003)



(~ $(E/N^2)^{1/4}$ can be shown analytically at low and high energy regions)

E. Rinaldi

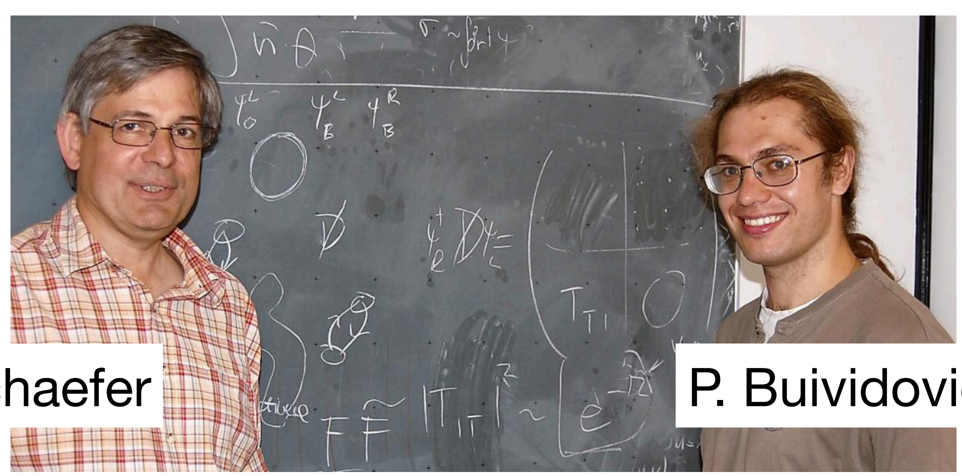
E. Berkowitz

- Quantum simulation?
- Classical Yang-Mills?
- Classical Yang-Mills + quantum effect?
- Or better ideas?

Buividovich-MH-Shaefer, in progress; EPJ Web Conf. 2018

Berkowitz-MH-Maltz, PRD 2016

Rinaldi-Berkowitz-MH-Maltz-Vranas, JHEP 2018



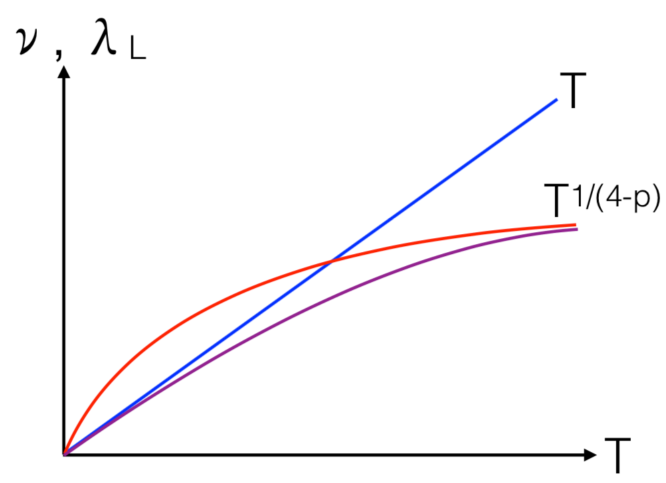
A. Schaefer

P. Buividovich

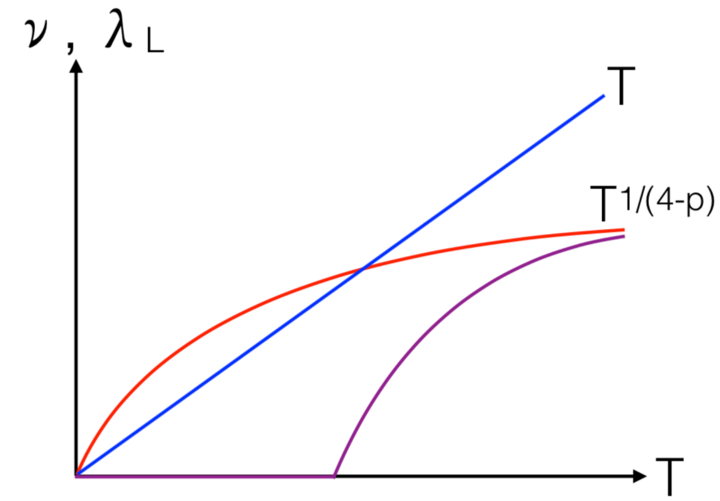
J. Maltz

P. Vranas

- Can we confirm the expected quantum corrections?



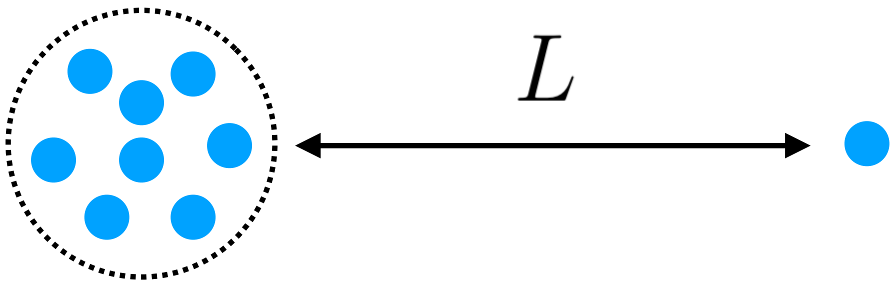
SYM



pure YM +scalar

'Gaussian state approximation' supports this picture.

- Can we study black hole evaporation?



- SUSY assists the emission of D-branes.
- Effective potential acting on a probe brane can be estimated from Euclidean theory by Monte Carlo simulation.

Summary

- A lot of things to do.
- Let’s make a black hole in a lab!
- Classical YM is already interesting and useful.
- Quantum effects in the weak coupling region is within reach.
- ‘Hawking radiation’ at high temperature is within reach.
- Your ideas will be appreciated!