Why does black hole describe the deconfinement phase?

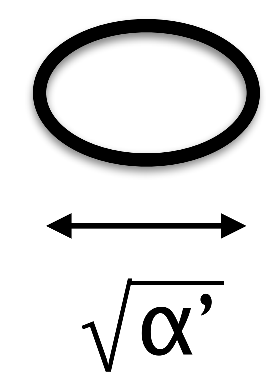
Masanori Hanada
花田 政範
Hana Da Masa Nori

YITP, Kyoto U. & SITP, Stanford U.

M.H.-Hyakutake-Nishimura-Takeuchi, PRL (2009)
M.H.-Hyakutake-Ishiki-Nishimura, Science (2014)
M.H.-Maltz-Susskind, hep-th (2014)
+ work in progress.

Maldacena's conjecture: deconfining phase = black hole

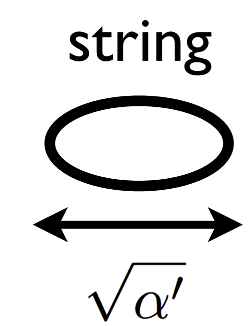
Super Yang-Mills		**STRING**
$1/\lambda$	$\longleftrightarrow$	α'/R_{BH}^2
$g_{YM}^2 \sim 1/N$		g_s



$\lambda=\infty$, $N=\infty$ corresponds to supergravity.

assumed to be correct without proof, and applied to QGP etc

SYM	STRING
large-N, strong coupling	SUGRA
large-N, finite coupling	tree-level string (SUGRA+α’)
finite-N, finite coupling	Quantum string (g_{string}>0)



SYM$_{\text{difficult}}$	STRING
large-N, strong coupling	SUGRA easier
large-N, finite coupling	tree-level string (SUGRA+α') more difficult
finite-N, finite coupling	Quantum string (g_{string}>0) very difficult

SYM difficult

STRING

large-N,
strong coupling

SUGRA
easier

large-N,
finite coupling

tree-level string
(SUGRA+α')
more difficult

finite-N,
finite coupling

Quantum string
(g_{string}>0)
very difficult

SYM$_{\text{difficult}}$		STRING
large-N, strong coupling	←	SUGRA easier
large-N, finite coupling	→	tree-level string (SUGRA+α') more difficult
finite-N, finite coupling	→	Quantum string (g_{string}>0) very difficult

The opposite (actually the *original*) direction of the dictionary is useful!

SYM$_{\text{difficult}}$ STRING

large-N, strong coupling ← SUGRA easier

large-N, finite coupling ⇄ tree-level string (SUGRA+α') more difficult

finite-N, finite coupling ⇄ Quantum string (g_{string}>0) very difficult

….and string should tell us more about real SU(3) QGP.

(1) Is it correct?

(1-1)Is it correct only at large-N, strong coupling?

(supergravity, or Einstein gravity)

(1-2) Or correct including1/λ and 1/N corrections?

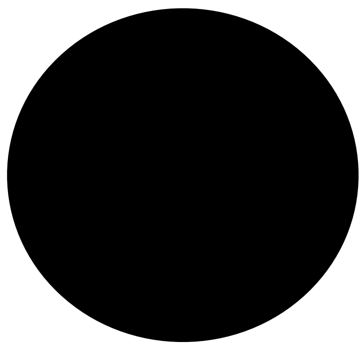
(superstring theory)

(2) If correct, why? Can we understand it intuitively?

Important problems for particle & nuclear physics, because

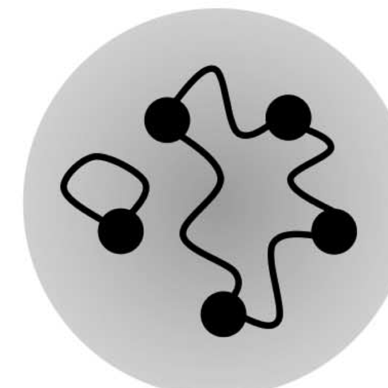
— We want to understand quantum gravity, which is an important piece of physics beyond standard model.

— We want to understand thermalization of QGP.



IIB string on AdS_5
(black 3-branes)

equivalent



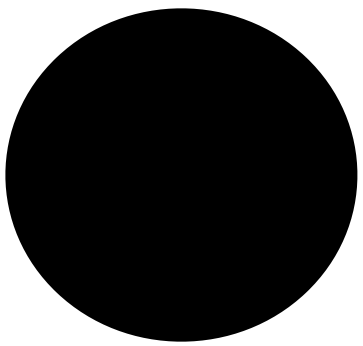
4d N=4 SYM
(D3-branes + strings)

(Maldacena1997)

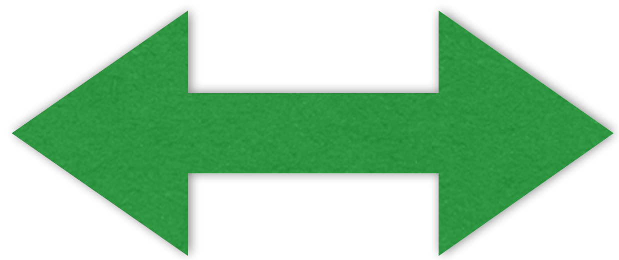
numerically demanding

Black hole = bunch of D0-branes

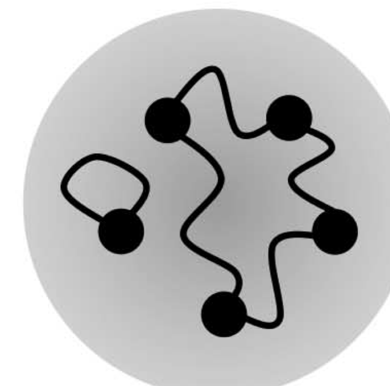
(+ strings between them)



IIA string around
black 0-brane
(near horizon)



equivalent



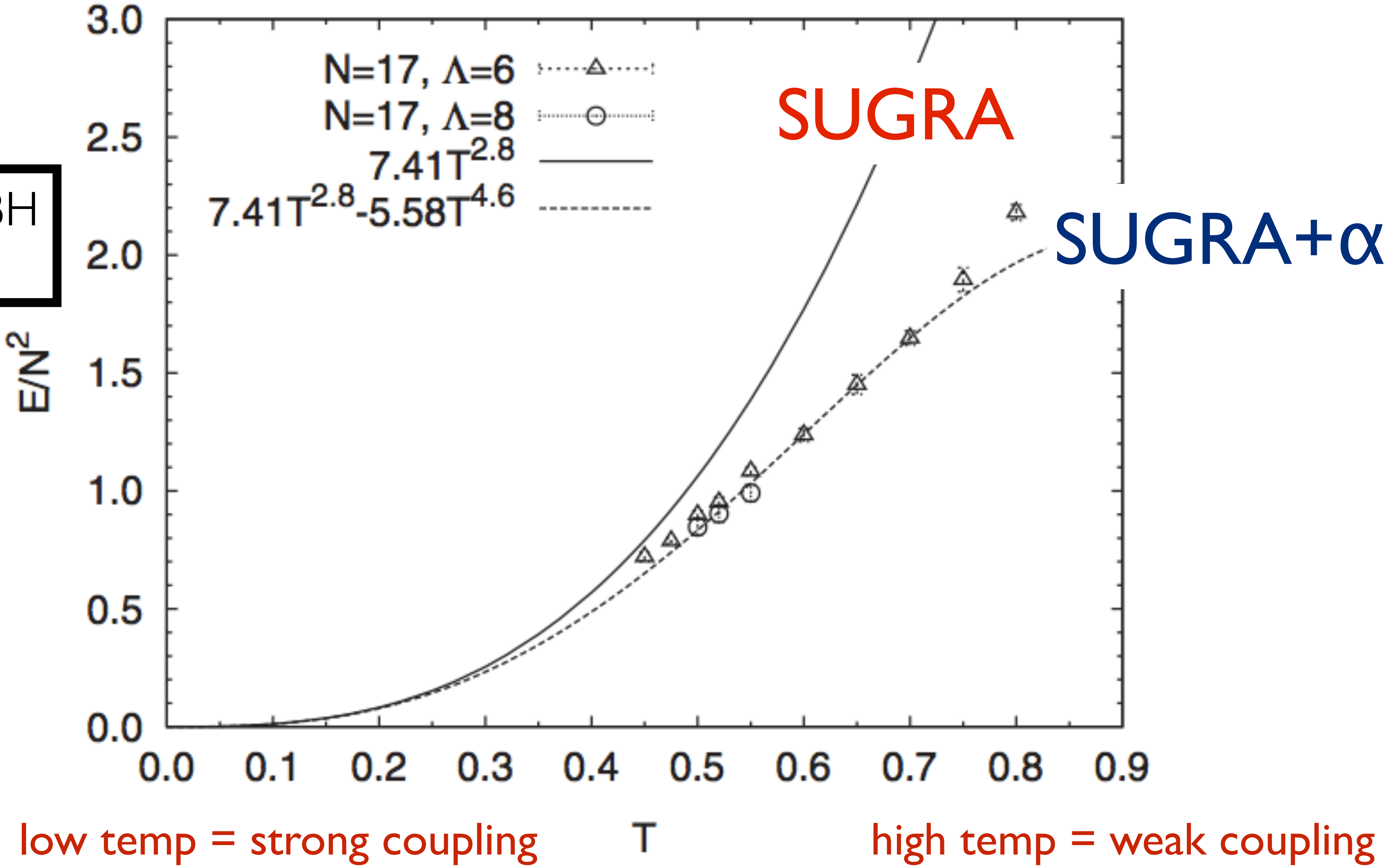
(0+1)-d maximal SYM

(Maldacena 1997; Itzhaki-Sonnenschein-Maldacena-Yankielowicz 1998)

Quantitative test is possible by studying SYM numerically.

Is it correct?

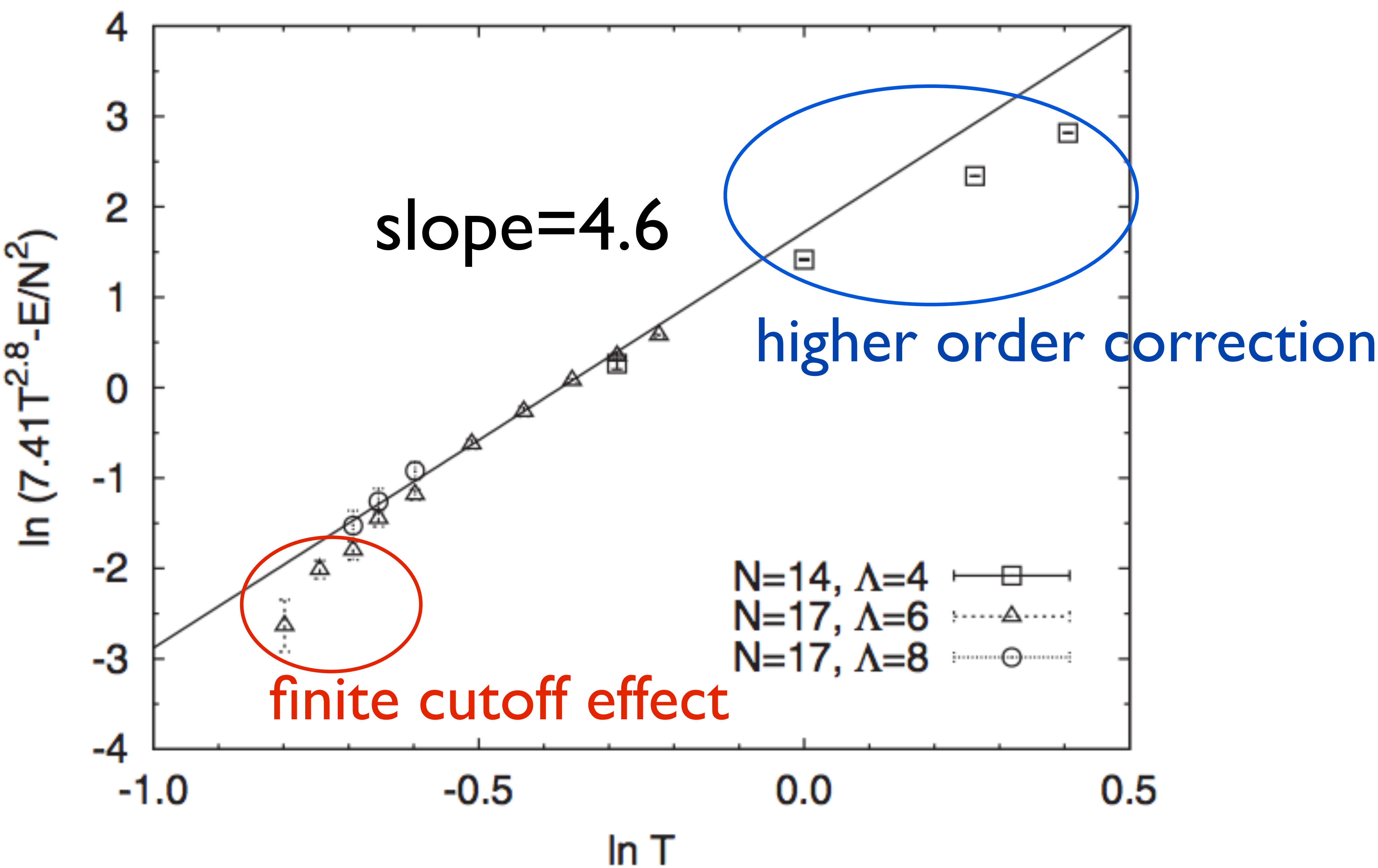
energy of BH and SYM



M.H.-Hyakutake-Nishimura-Takeuchi, PRL 2009

($\lambda^{-1/3}T$: dimensionless effective temperature)

Maldacena conjecture is correct at finite coupling & temperature!



M.H.-Hyakutake-Nishimura-Takeuchi, PRL 2009

1/N correction

Dual gravity prediction (Y. Hyakutake 2013)

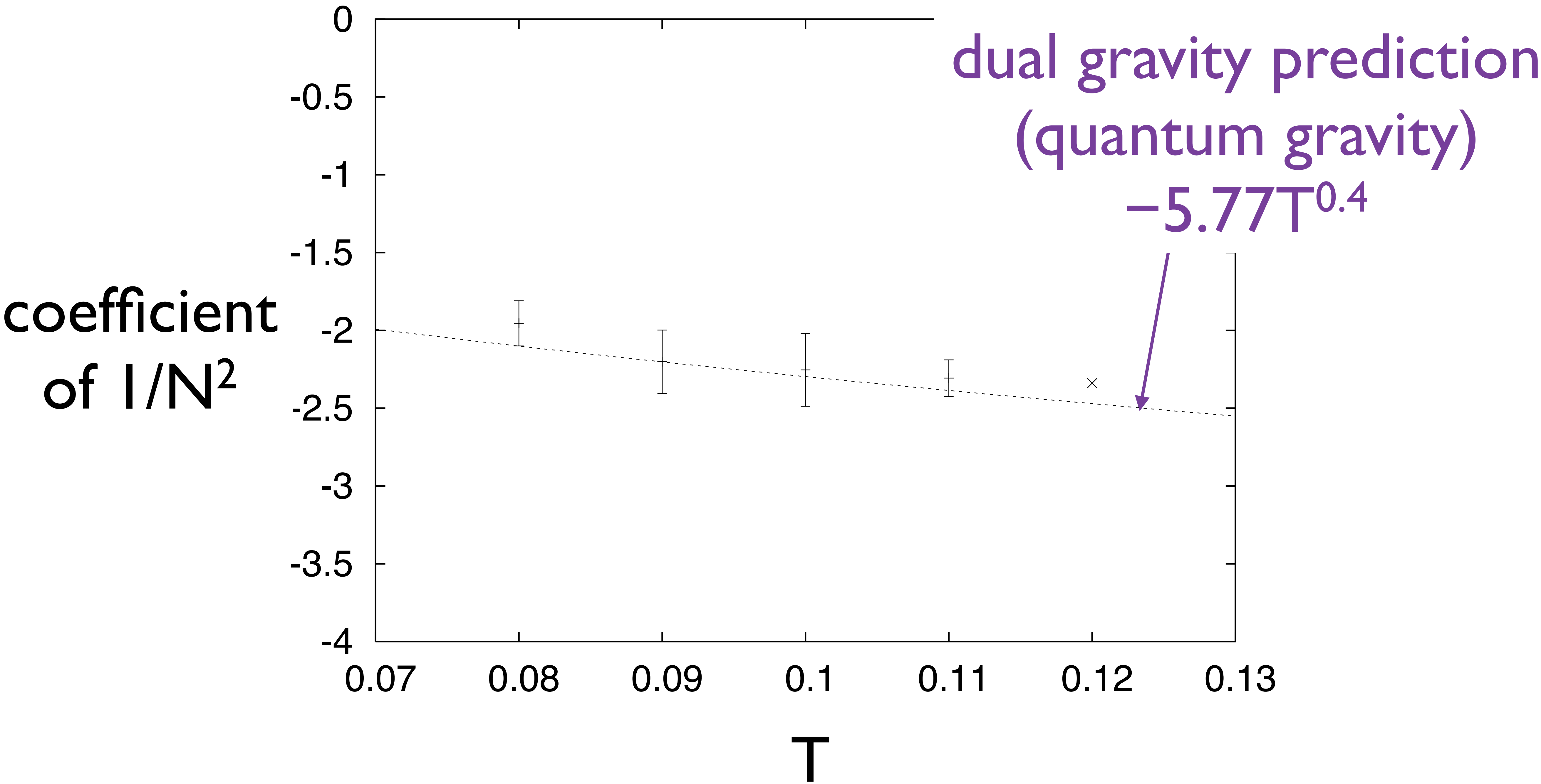
$$E/N^2 = 7.41T^{2.8} - 5.58T^{4.6} + \ldots.$$

$$\left.\begin{aligned} &+(1/N^2)(-5.77T^{0.4} + aT^{2.2} + \ldots) \\ &+(1/N^4)(bT^{-2.6} + cT^{-2.0} + \ldots) \\ &+\ldots.. \end{aligned}\right\} \begin{array}{l} \textit{QUANTUM} \\ \text{string effect} \end{array}$$

Can it be reproduced from YM?

Maldacena conjecture is correct at finite-N !

(at least to graviton 1-loop)



M.H.-Hyakutake-Ishiki-Nishimura, Science 2014

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | F

News & Comment > News > 2013 > December > Article

NATURE | NEWS

Simulations back up theory that Universe is a hologram

A ten-dimensional theory of gravity makes the same predictions as standard quantum physics in fewer dimensions.

‘most-read news in 2013’ @ nature.com

1,200,000 hits in less than one week

Gauge/gravity duality in tabloids


Find a Job | Amazon Videos | Feedback Like 613k Follow @MailOnline Wednesday, Dec 18 2013 12AM 60°F 3AM 53°F 5-Day Forecast

Mail Online

Home | U.K. Home | News | Sport | U.S. Showbiz | Femail | Health | Science | Money | Video | Travel | Columnists

Science Home | Pictures | Gadgets Gifts and Toys Store Login

Are we living in a HOLOGRAM? Physicists believe our universe could just be a projection of another cosmos

- Holographic principle claims gravity comes from thin, vibrating strings
- These strings are holograms of events that take place in a flatter cosmos
- According to this theory, everything we experience can be described as events that take place in this flatter location
- This is the first time the validity of the model has been mathematically tested

By ELLIE ZOLFAGHARIFARD

PUBLISHED: 08:03 EST, 12 December 2013 | UPDATED: 09:43 EST, 12 December 2013

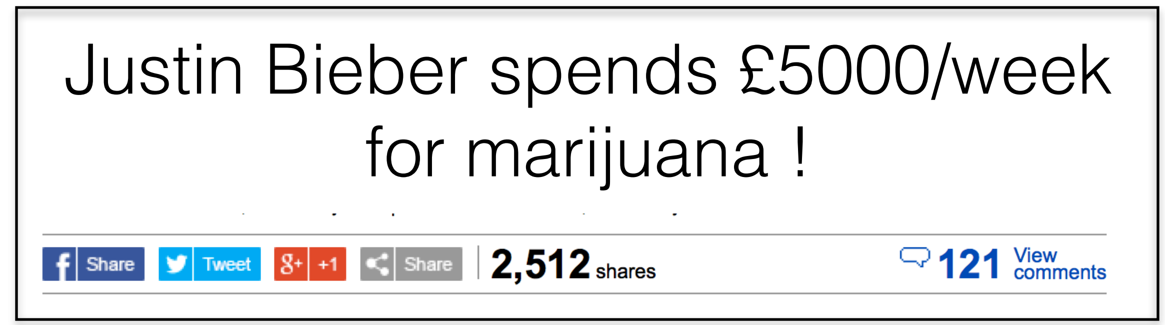
Share Tweet +1 Share 84,699 shares 1015 View comments

The universe is a hologram and everything you can see - including this article and the device you are reading it on - is a mere projection.

This is according to a controversial model proposed in 1997 by theoretical physicist Juan Maldacena.

Until now the bizarre theory had never been tested, but recent mathematical models suggest that the mind-boggling principle could be true.

(Daily Mail, 12 Dec 2013)


Justin Bieber spends £5000/week for marijuana !

Share Tweet +1 Share 2,512 shares 121 View comments

shared 34 timesmore than Justin Bieber's marijuana scandal.

1600 times more than Lady Gaga

O(1,000,000) shares/tweets/comments

not counted as citations?

Other Simulations

- Two-point functions (M.H.-Nishimura-Sekino-Yoneya, PRL 2010, JHEP 2011)
- Polyakov loop (Anagnostopoulos-M.H.-Nishimura-Takeuchi, PRL 2008; M.H.-Miwa-Nishimura-Takeuchi, PRL 2009)
- 2d SYM vs black string (Catterall-Joseph-Wiseman, JHEP 2010)
- 4d SYM vs AdS_5 (Honda et al 2011–, Catterall et al 2012–)

Why is it correct?

Can we understand it intuitively?

microscopic descriptions of the black hole (black brane)

(1) D-branes + open strings

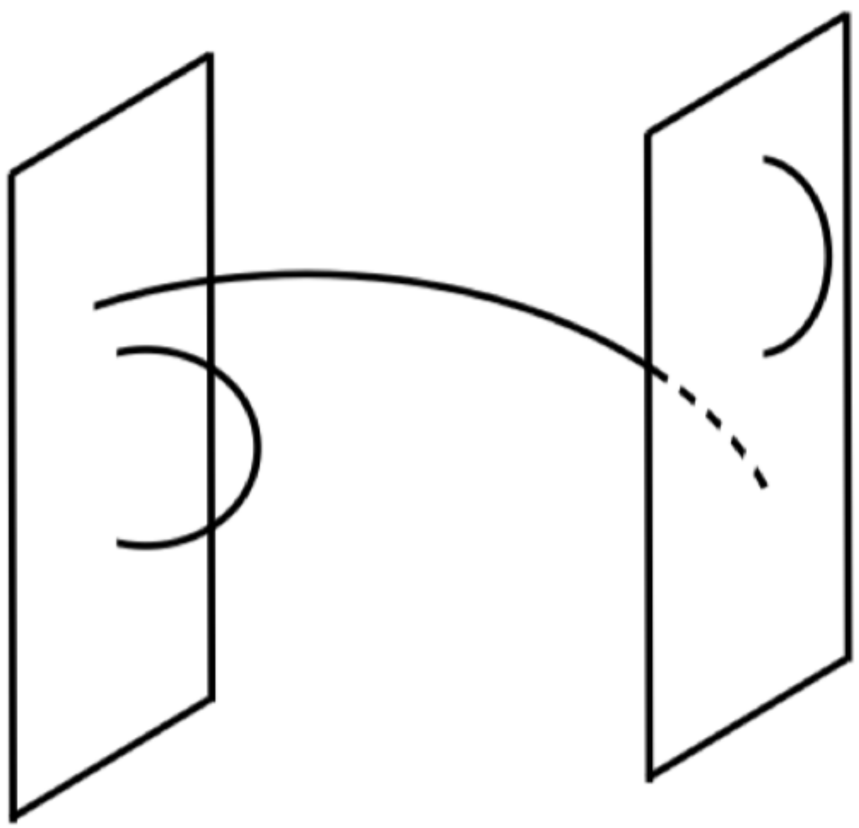
Polchinski, …

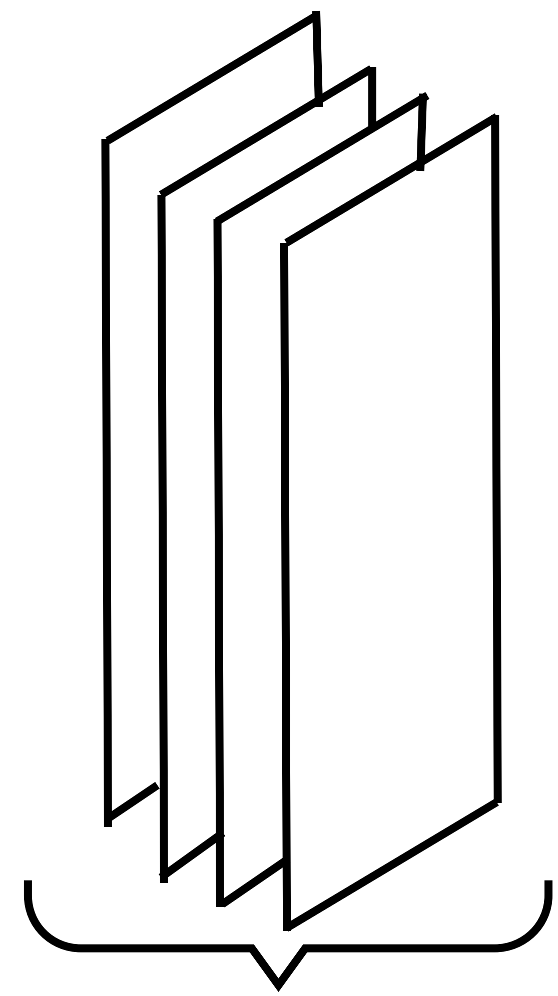
(2) condensation of closed strings

Susskind, Horowitz-Polchinski, …

BH = D-branes + open strings

U(N) YM



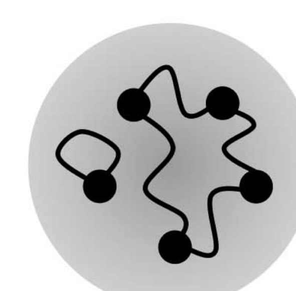


U(2) YM

N Dp-branes

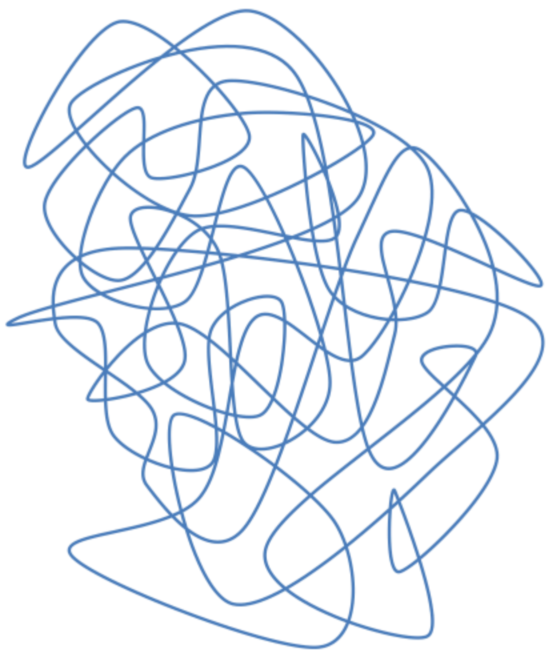
(i,j)-component of matrices
= string between i-th and j-th D-branes

large N →heavy →BH



Black hole from closed string

(e.g. Susskind 1993)

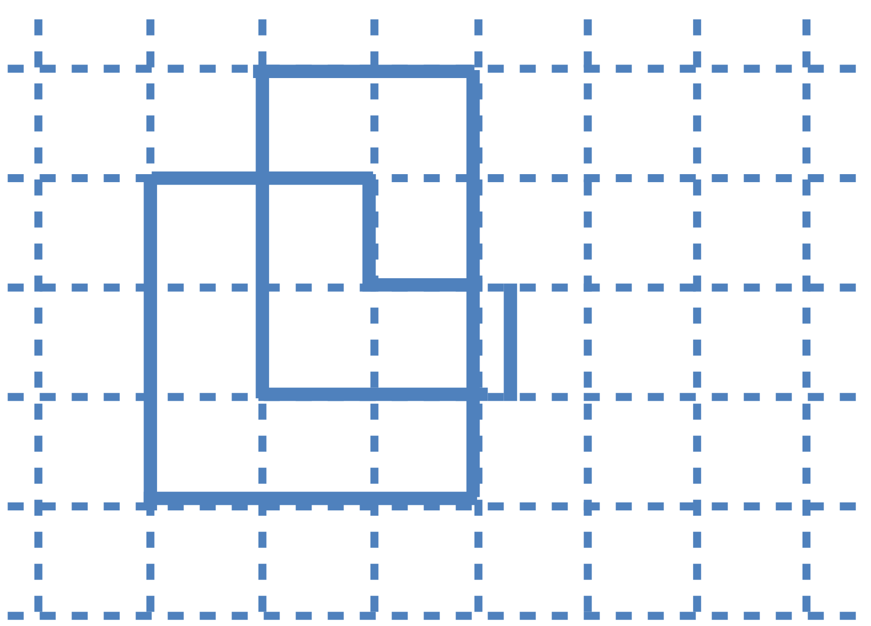


Consider a long, winding string with length L.

energy = tension × L

entropy $\sim$ L

when L >> 1, huge energy and entropy are packed in a small region → <u>*black hole*</u>



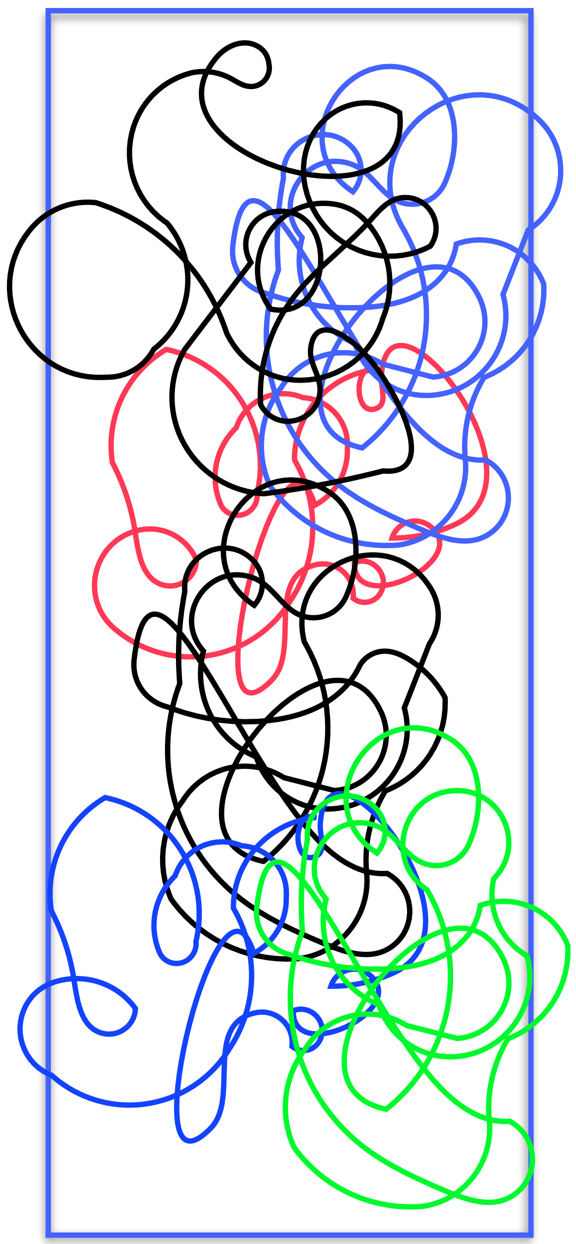
On D-dim square lattice,

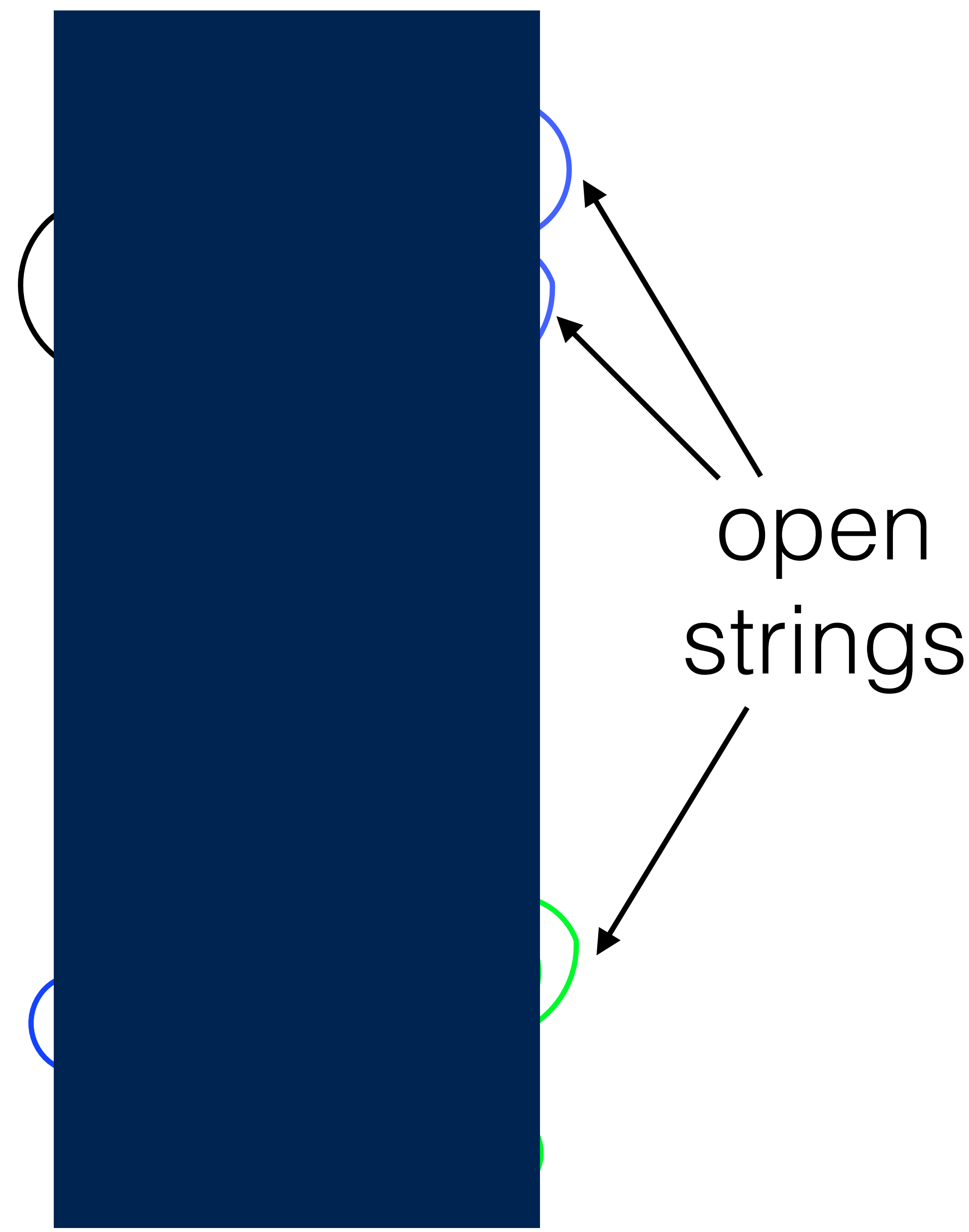
# of possible shapes $\sim (2D-1)^L$

entropy $\sim L \times \log(2D-1)$

How are they related?

long, winding strings = black brane + open strings





The meaning of N (# of D-branes) becomes clear later.

Gauge theory description

confining phase: ’t Hooft, 1974

deconfining phase: M.H.-Maltz-Susskind, 2014

Lattice gauge theory description at strong coupling

Understand it by using the Hamiltonian formulation of lattice gauge theory (Kogut-Susskind, 1974)

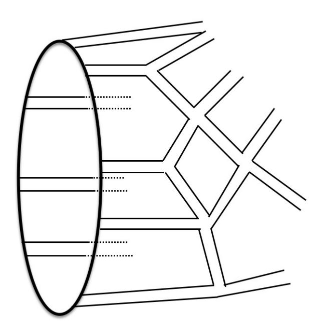
$$H = \frac{\lambda N}{2} \sum_{\vec{x}} \sum_{\mu} \sum_{\alpha=1}^{N^2} \left(E^{\alpha}_{\mu,\vec{x}}\right)^2 + \frac{N}{\lambda} \sum_{\vec{x}} \sum_{\mu<\nu} \left(N - \mathrm{Tr}(U_{\mu,\vec{x}} U_{\nu,\vec{x}+\hat{\mu}} U^{\dagger}_{\mu,\vec{x}+\hat{\nu}} U^{\dagger}_{\nu,\vec{x}})\right)$$

$$[E^{\alpha}_{\mu,\vec{x}}, U_{\nu,\vec{y}}] = \delta_{\mu\nu} \delta_{\vec{x}\vec{y}} \cdot \tau^{\alpha} U_{\nu,\vec{y}}$$

$$\sum_{\alpha=1}^{N^2} \tau^{\alpha}_{ij} \tau^{\alpha}_{kl} = \frac{\delta_{il}\delta_{jk}}{N^2}$$

Hilbert space is expressed by <u>Wilson loops.</u>

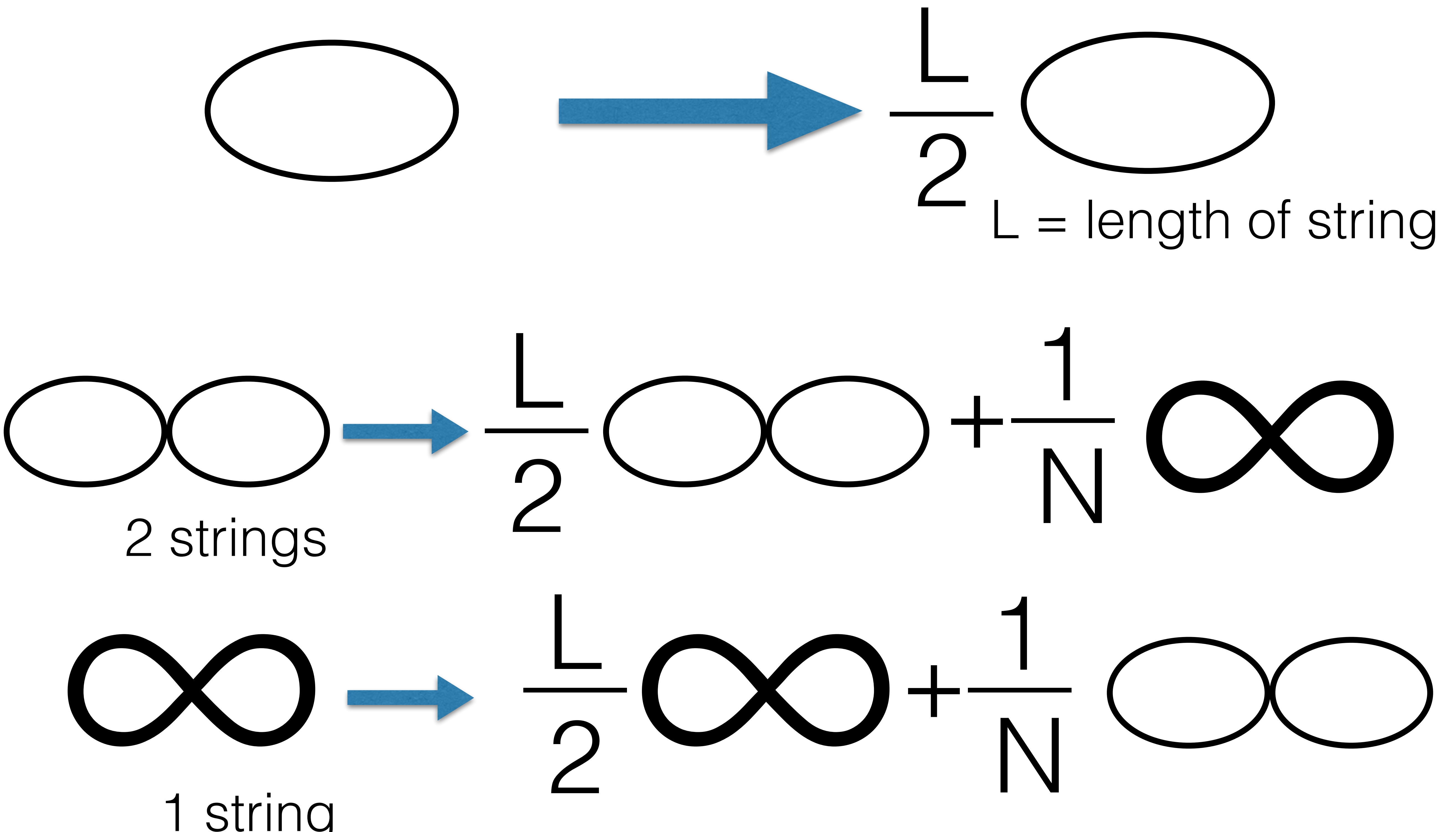
(closed string)

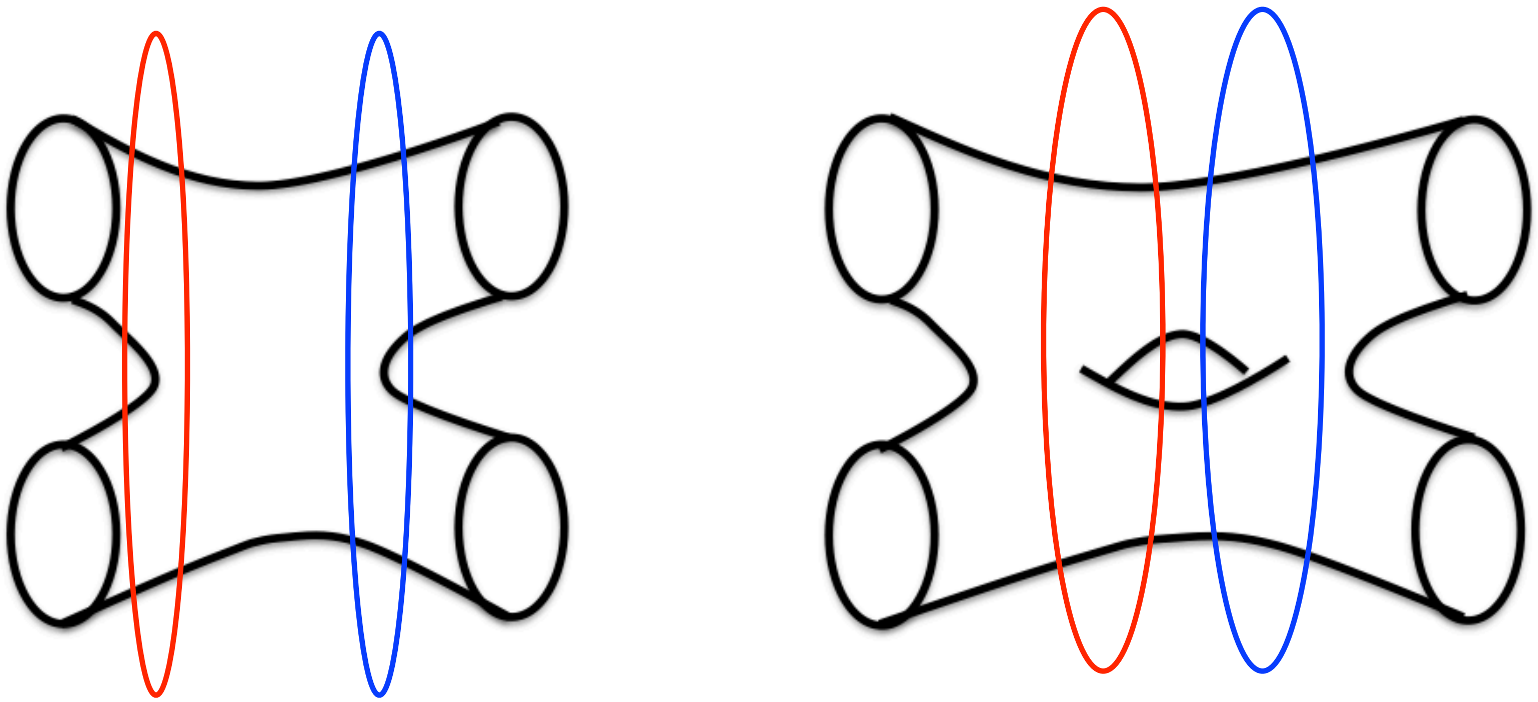


strong coupling limit

$$H = \frac{N}{2}\sum_{\vec{x}}\sum_{\mu}\sum_{\alpha=1}^{N^2}\left(E^{\alpha}_{\mu,\vec{x}}\right)^2$$

(λ=1 for simplicity)





splitting $\sim$ 1/N

joining $\sim$ 1/N

$1/N^2$ for each loop of closed strings

“large-N limit is the theory of free string”

Strings out of YM: <u>deconfining</u> phase

M.H.-Maltz-Susskind, 2014

Hilbert space is always the same. Why don't we express the deconfining phase by using Wilson loops?

- interaction (joining/splitting) is 1/N-suppressed

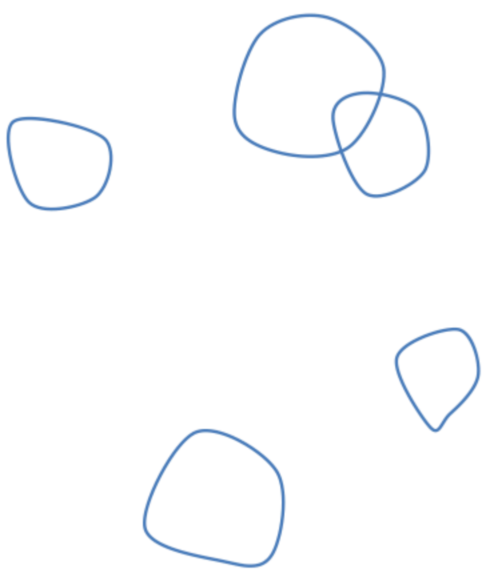
"large-N limit is the theory of free string"

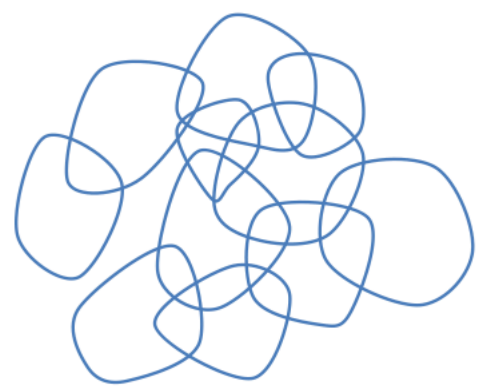
- It is true when L is $O(N^0)$. (→confining phase)

- In deconfinement phase, total length (energy) of the strings is $O(N^2)$ → number of intersections is $O(N^2)$ →interaction is **not** negligible

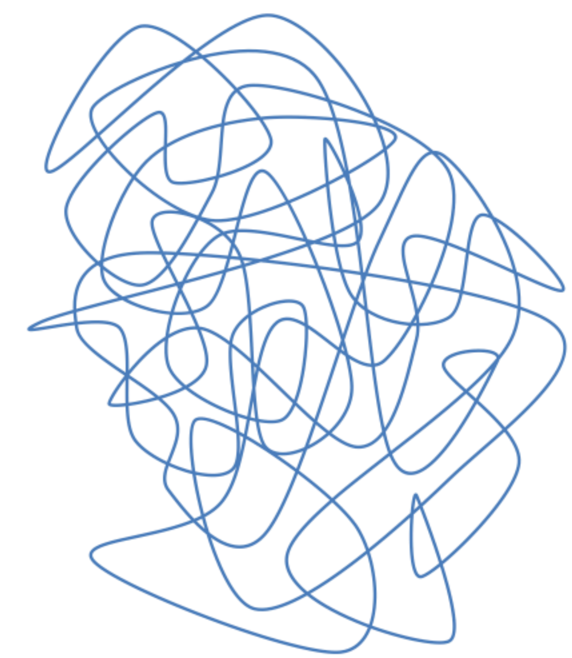
large-N limit is still very dynamical!

confining phase
= gas of short strings





long and winding string,
which is interpreted as BH,
appears



as the density of strings increase,
interaction between strings
becomes important,and…

Why $L \sim N^2$?

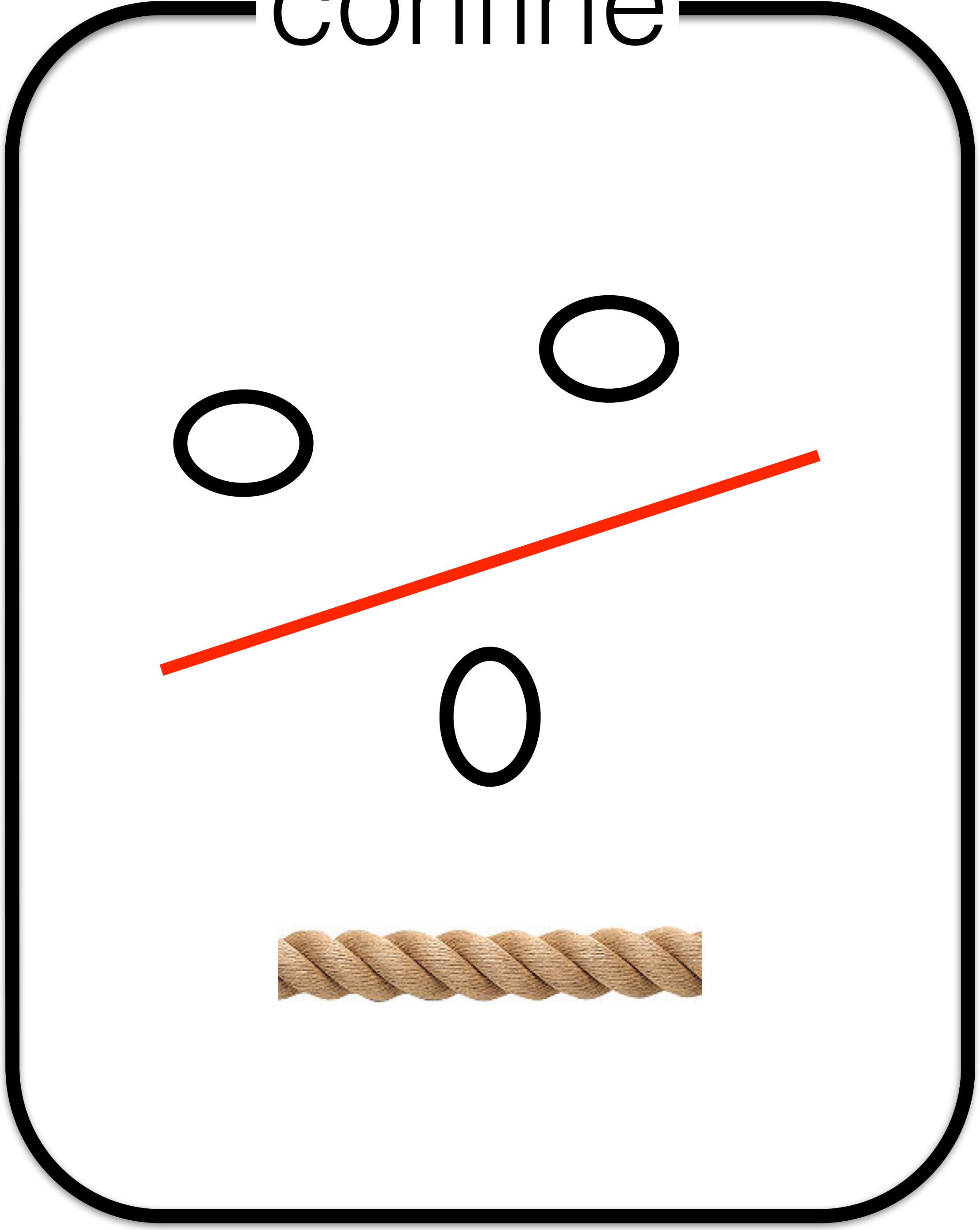
- Tr(UU'U''.....)

  length $\gtrsim$ N^2 $\rightarrow$ factorizes to shorter traces

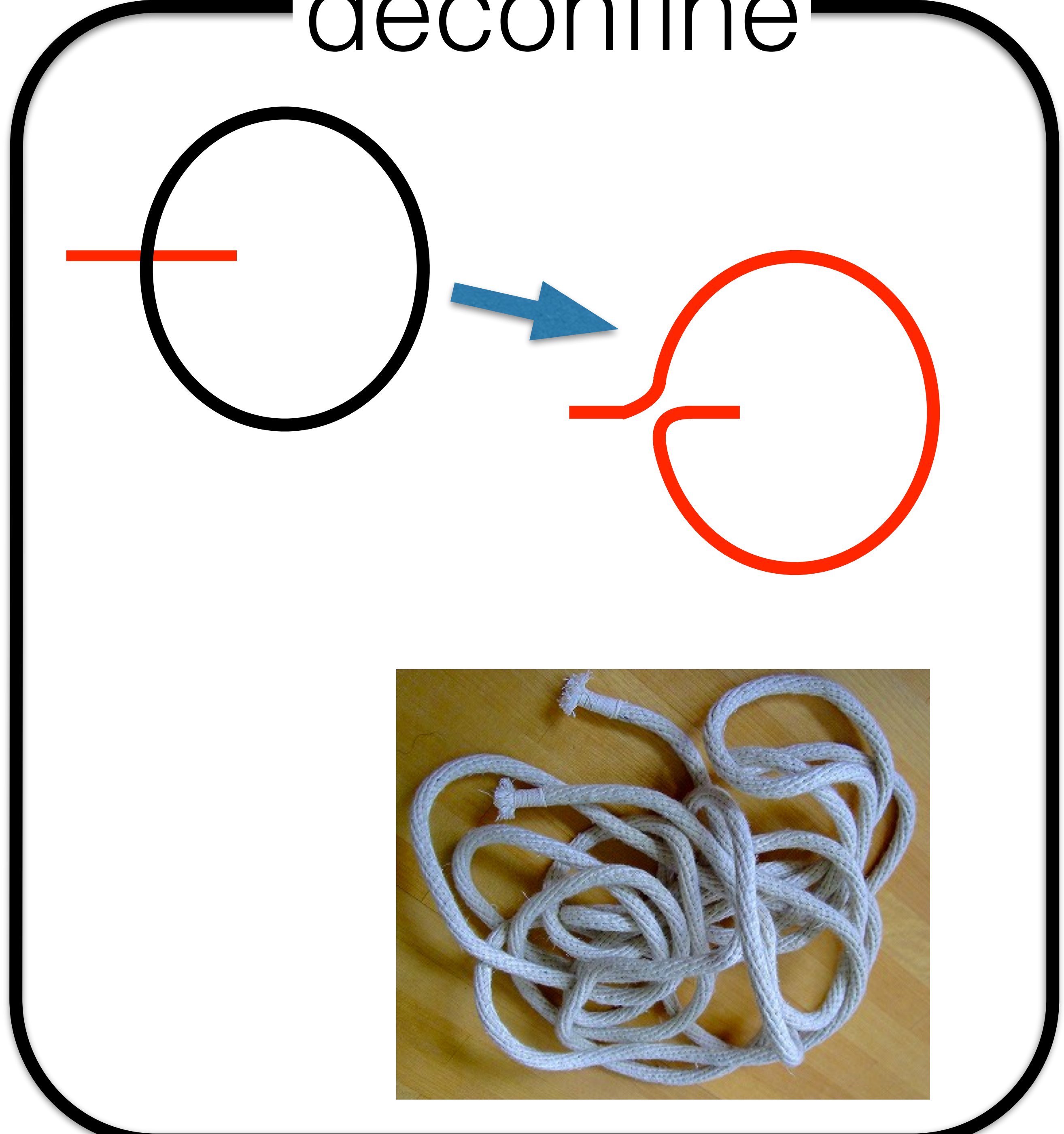
N^2 is the upper bound.
Beyond there, the counting changes;
<u>not much gain for the entropy.</u>

(de)confinement of probe charges

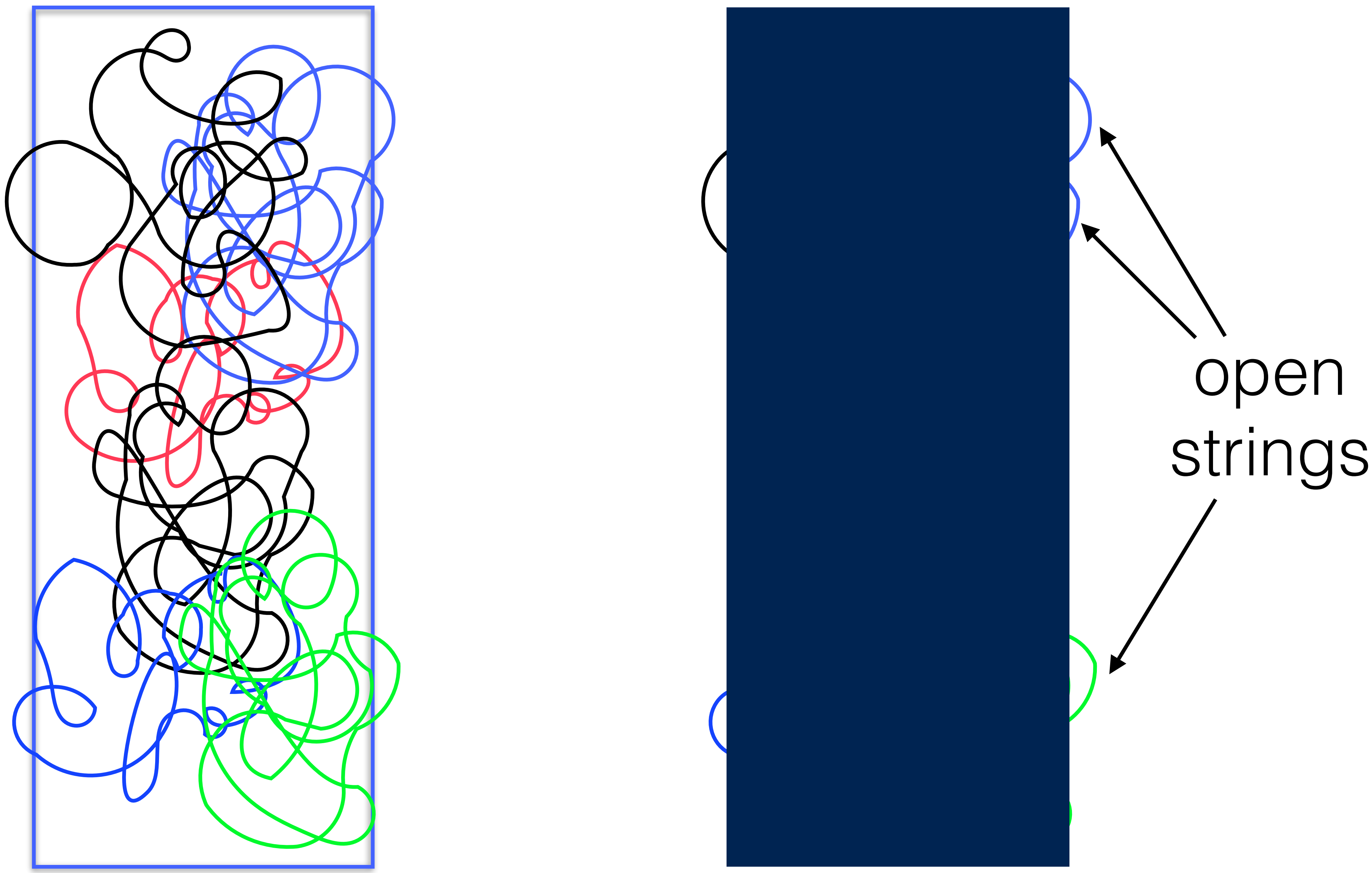
confine



deconfine



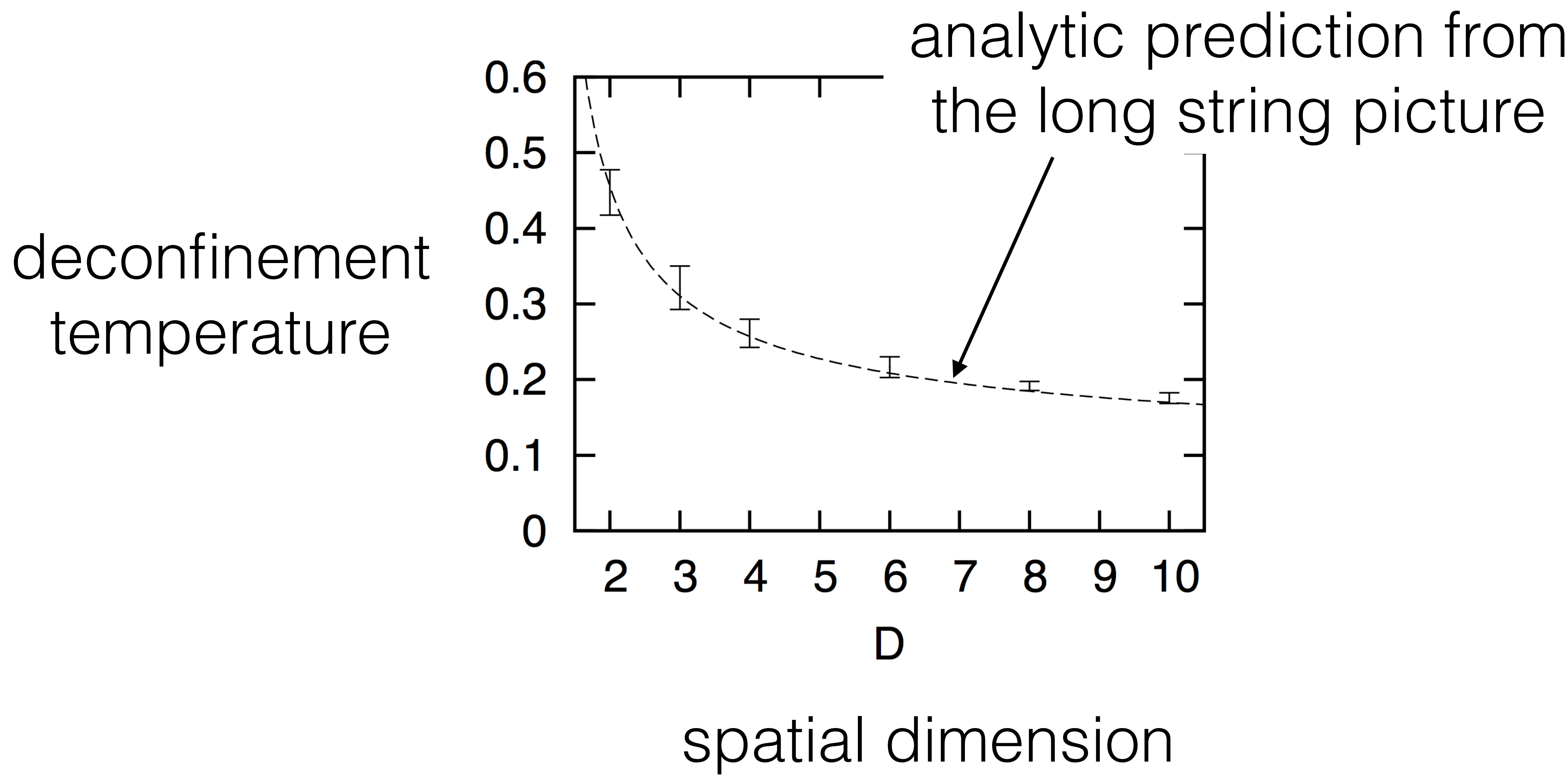
long, winding *QCD*-strings = black brane + open *QCD*-strings



open strings = Wilson lines, which have N color d.o.f at endpoints

→ black brane is made from N Dp-branes

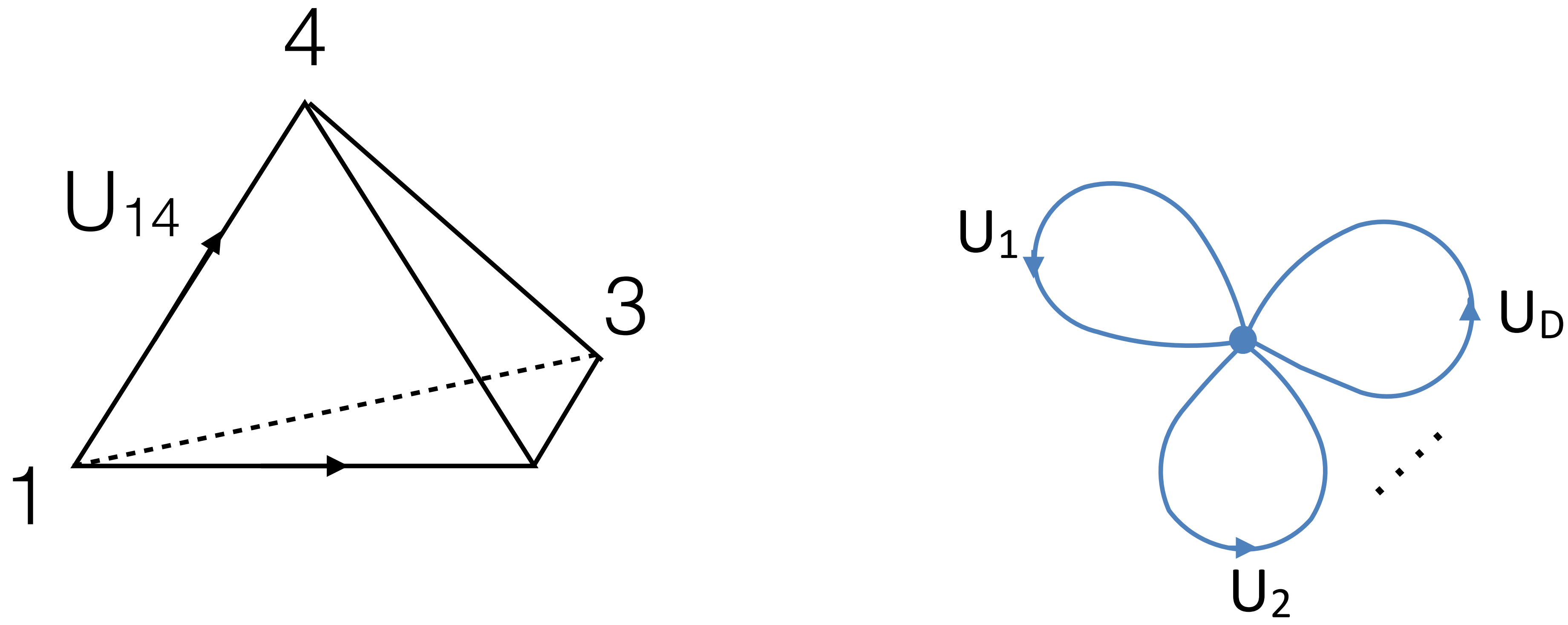
D-dim square lattice at strong coupling



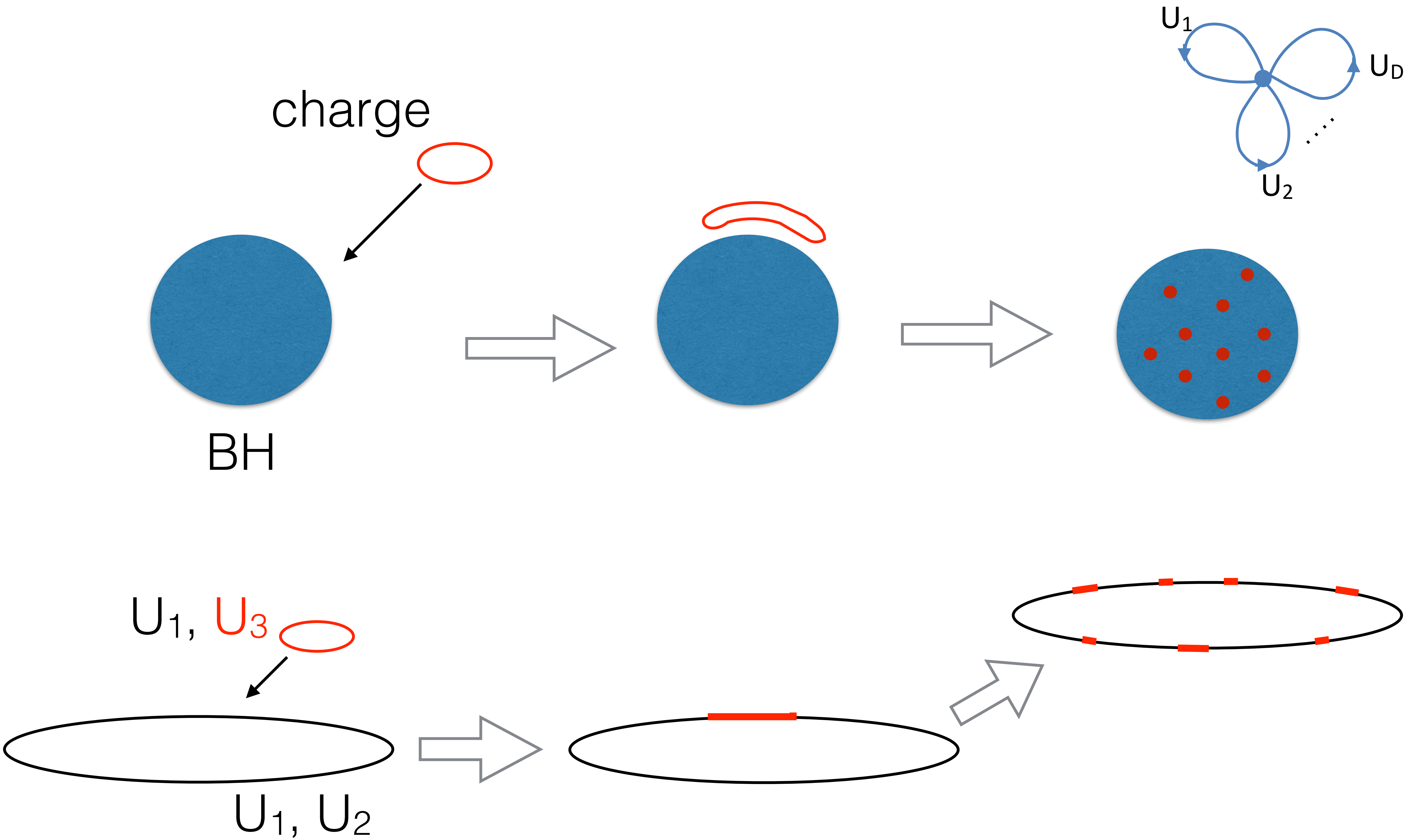
Real-time study of BH thermalization

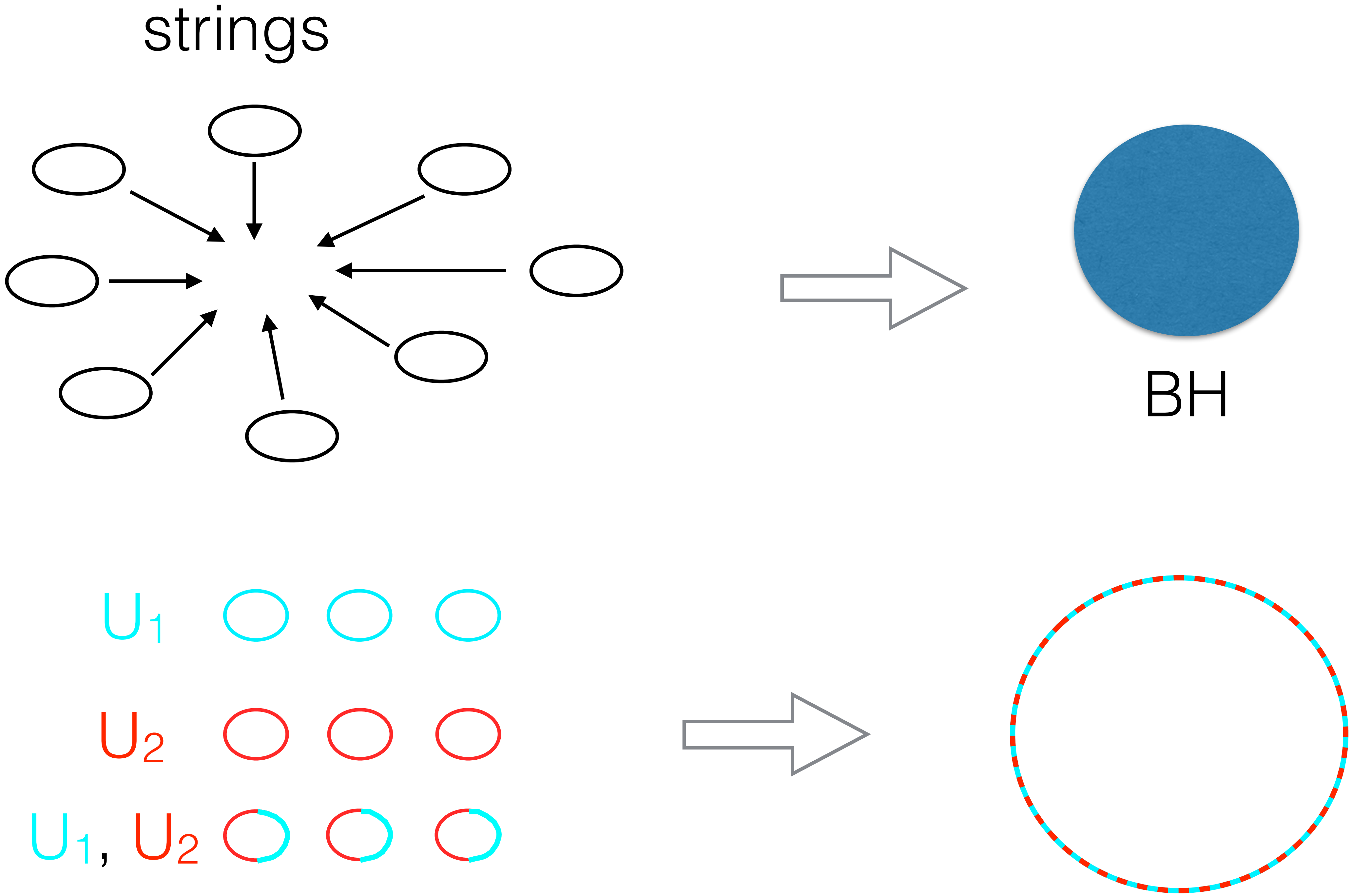
(in progress)

matrix models for black holes

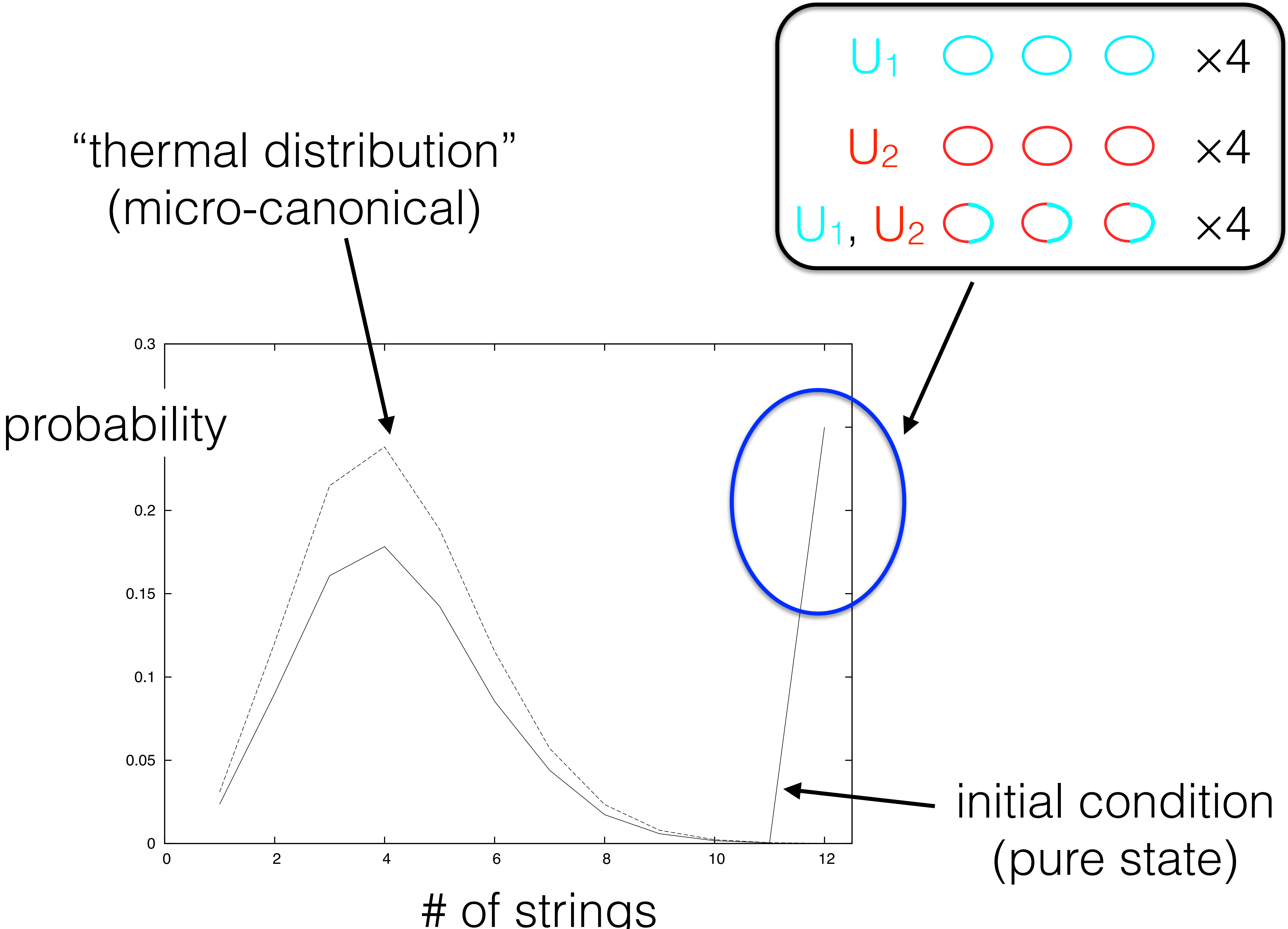


“thermalization” in the strong coupling limit



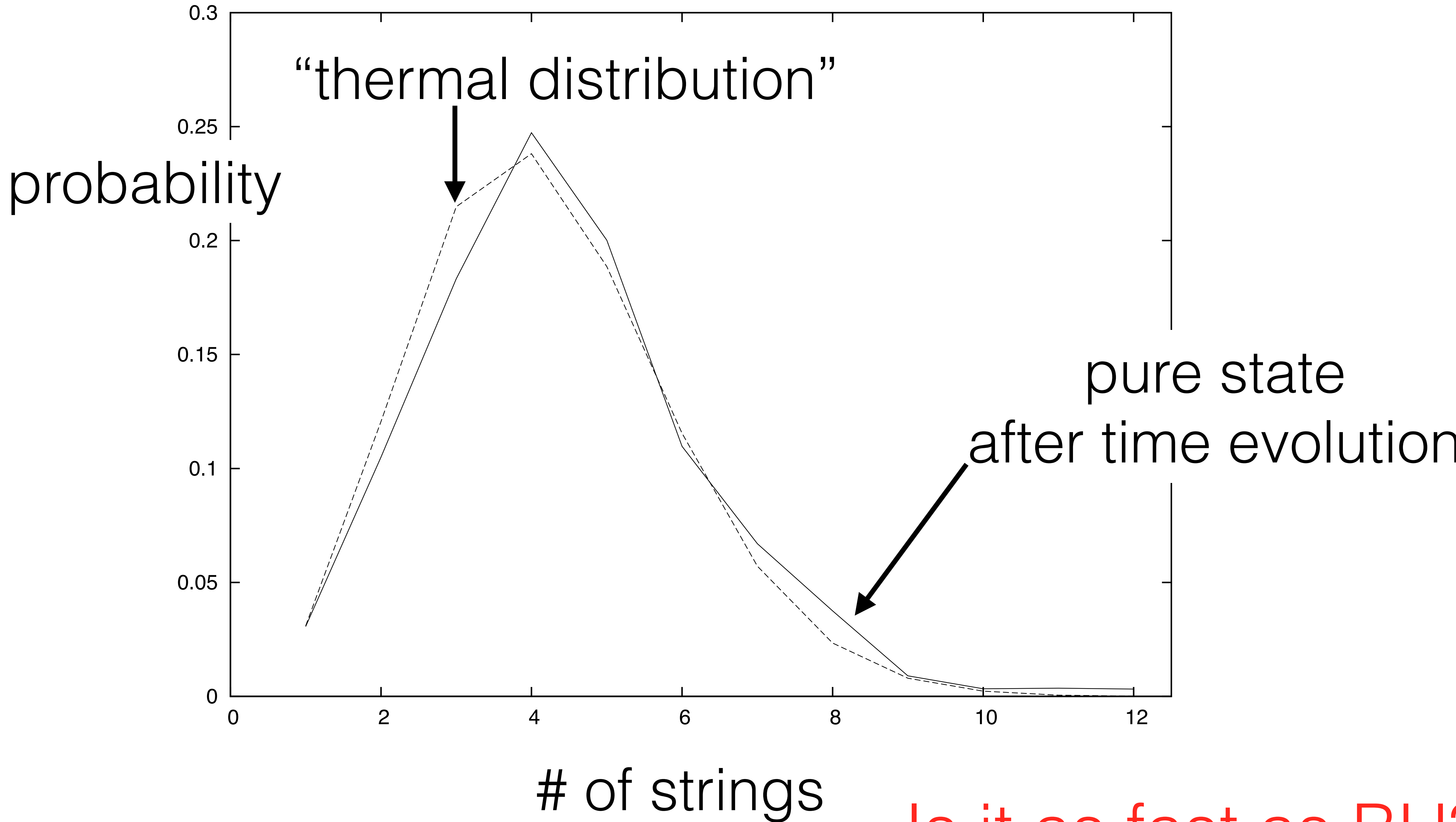


strings
BH
U1
U2
U1, U2



U1 ×4
U2 ×4
U1, U2 ×4
“thermal distribution”
(micro-canonical)
probability
0.3
0.2
0.15
0.1
0.05
0
0 2 4 6 8 10 12
initial condition
(pure state)
# of strings

it ‘thermalizes’ soon;
better thermalization with more links.

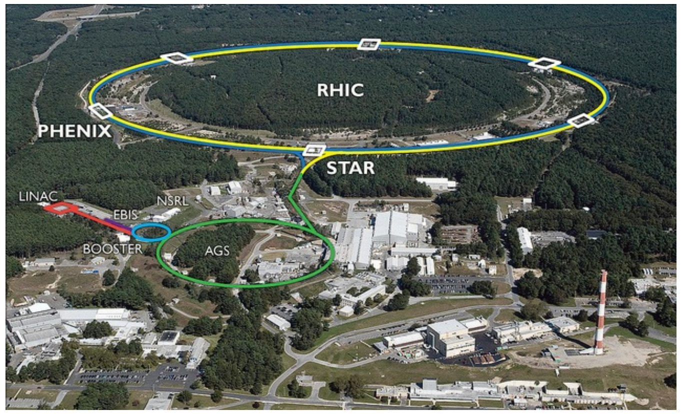


Is it as fast as BH?

conclusion(1)

Maldacena's conjecture is correct
at finite temperature,
including $1/\lambda$ and $1/N$ corrections,
at least to the next-leading order.

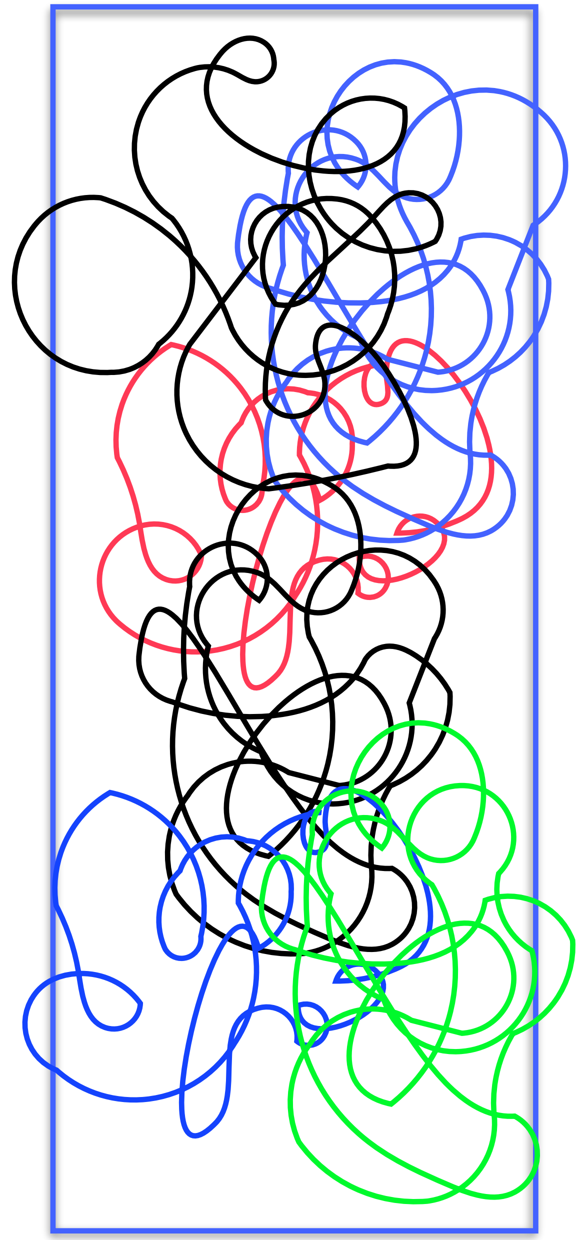
so, lattice/nuclear theorists can study
quantum gravity, by studying field theory.
You can do something string theorists cannot do.



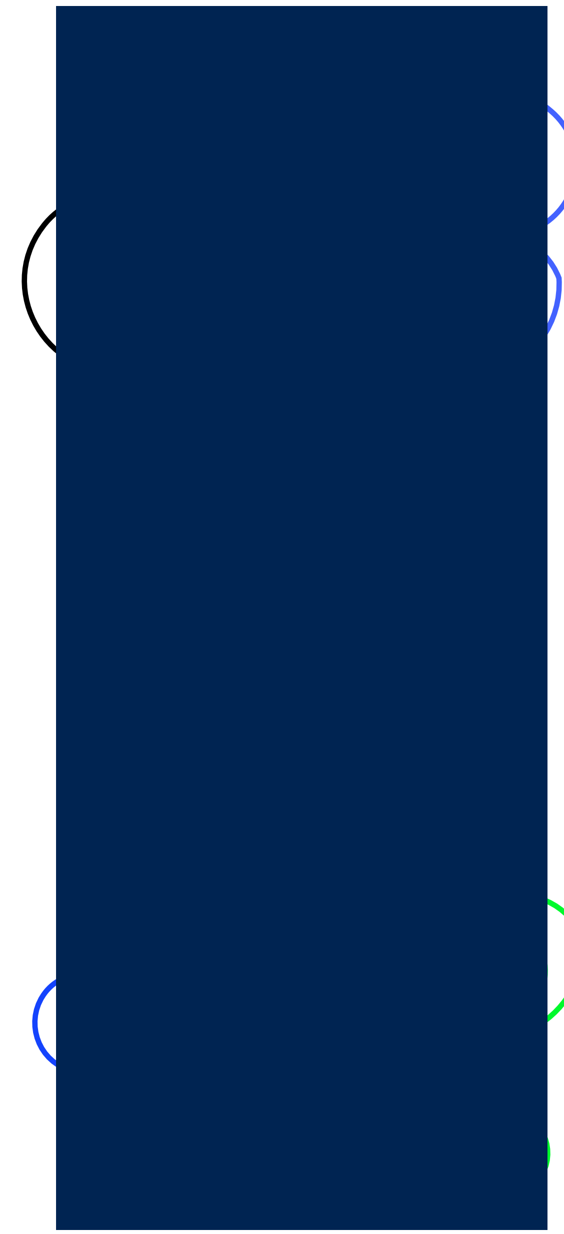
RHIC/LHC are machines for quantum gravity!

conclusion(2)

deconfinement phase =



=



Strong coupling limit contains the essence.

Time evolution can be studied.

Future directions

- Lattice gauge theory/nuclear physics + Black hole physics + Information science should provide us with new research field.

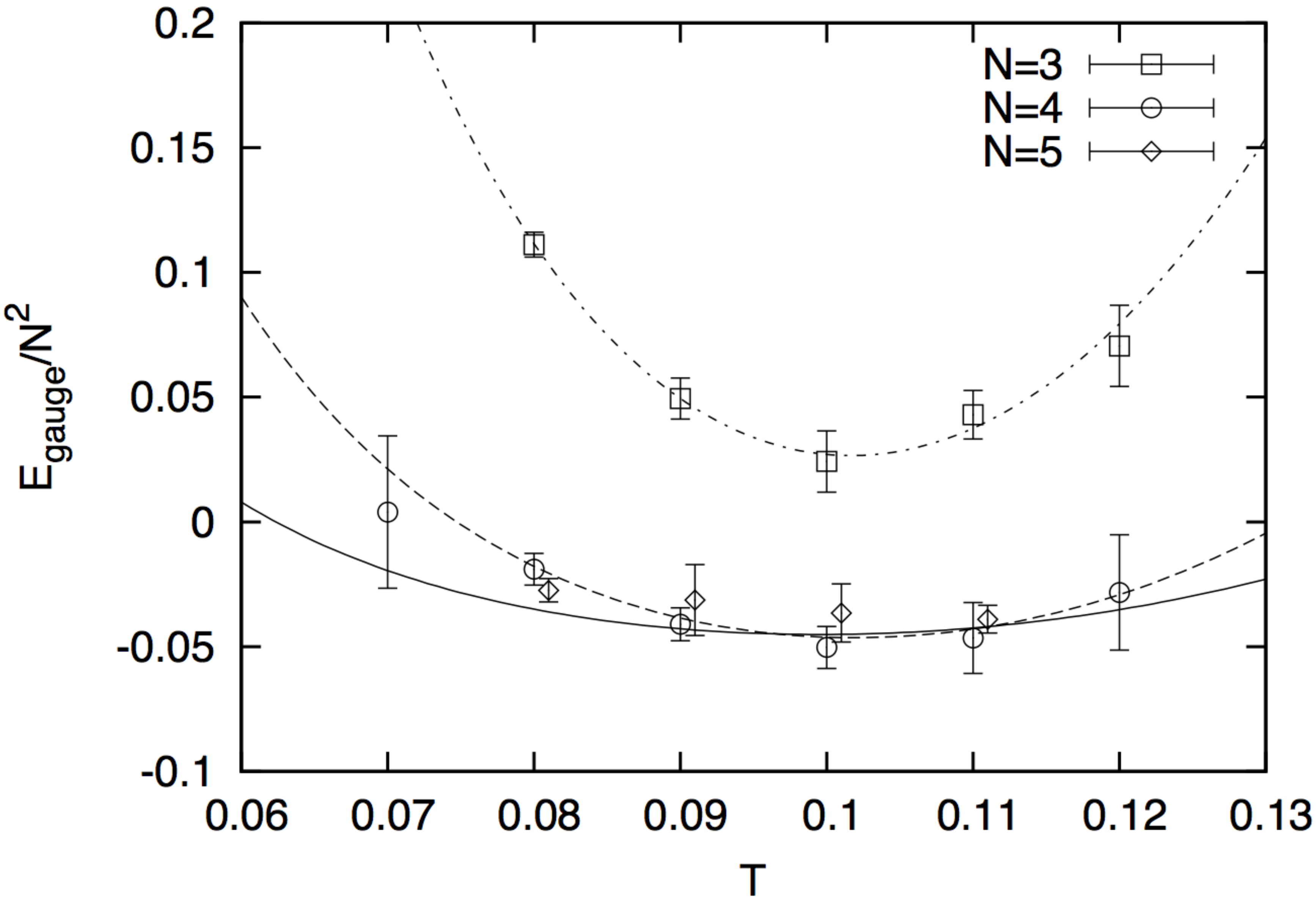
Complete solution of Hawking’s paradox

- Cosmology from string theory by lattice gauge theory/nuclear physics methods

New applications of lattice/Nuclear techniques!!

- Gravity calculation beyond supergravity (full string theory) will tell us about finite-N, finite-coupling gauge theory, especially the real-time dynamics.

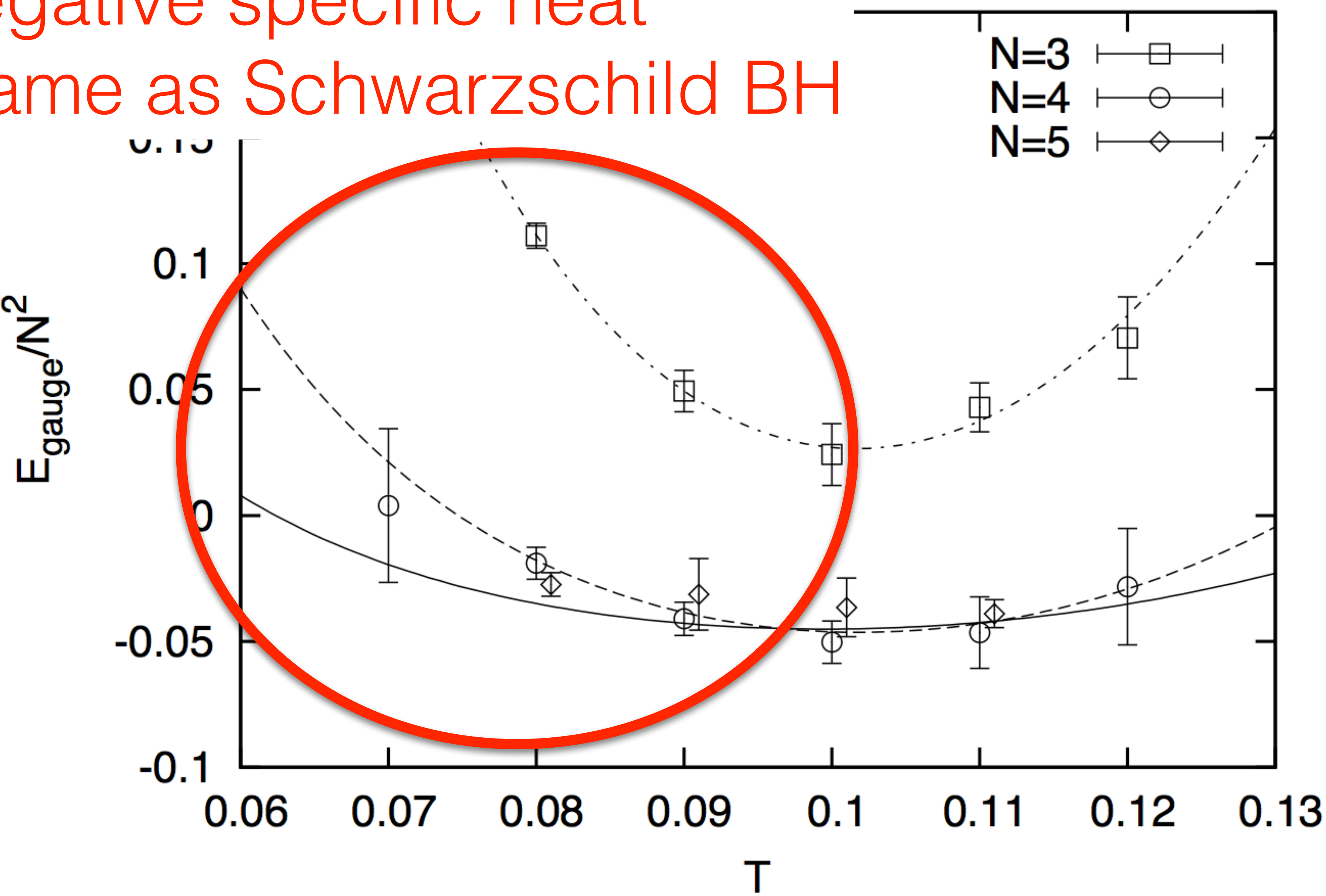
backup



M.H.-Hyakutake-Ishiki-Nishimura, Science 2014

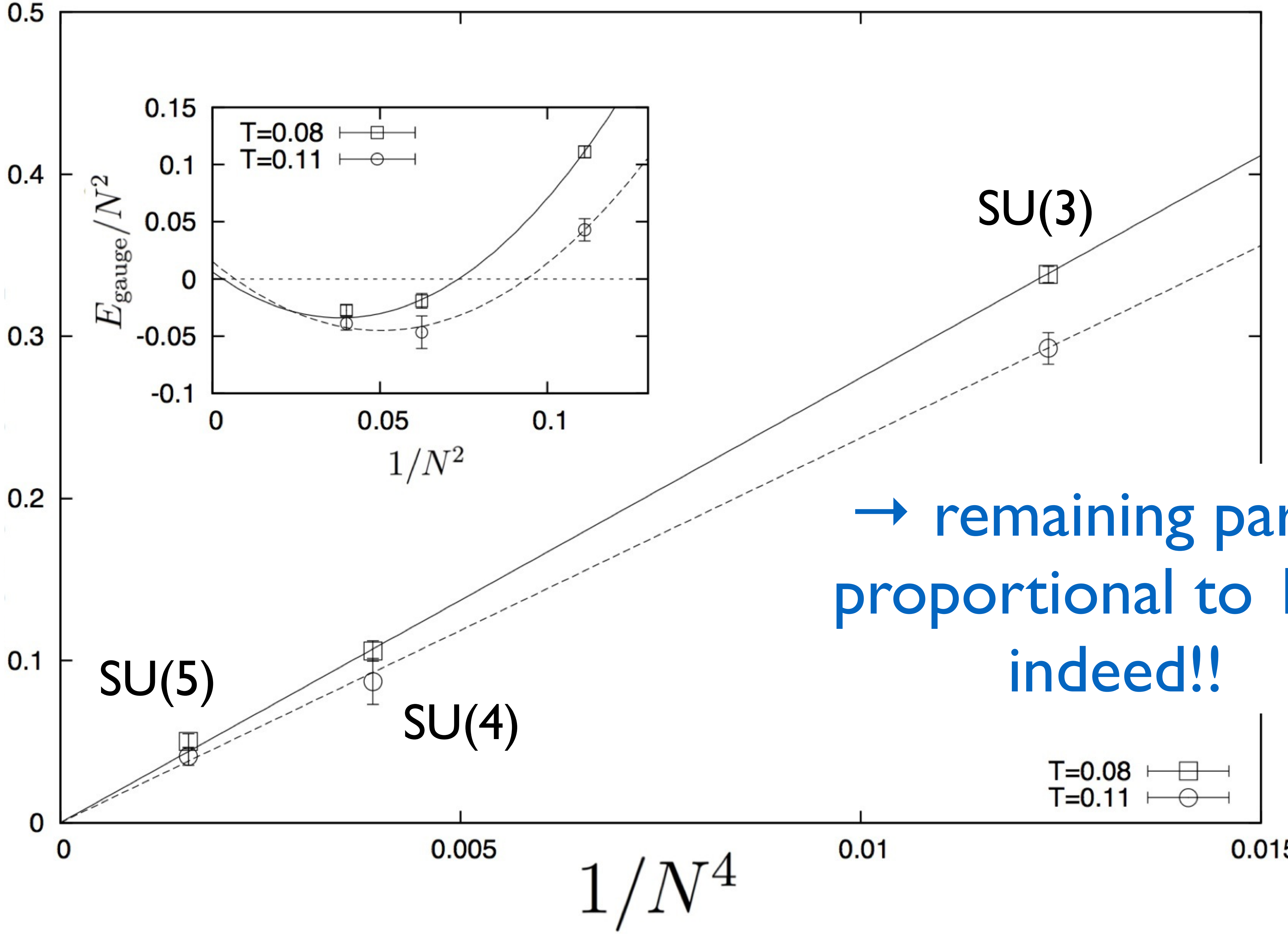
negative specific heat

→ the same as Schwarzschild BH



M.H.-Hyakutake-Ishiki-Nishimura, Science 2014

E/N^2 - $(7.41T^{2.8}$-$5.77T^{0.4}/N^2)$ vs. $1/N^4$



→ remaining part is proportional to $1/N^4$ indeed!!

M.H.-Hyakutake-Ishiki-Nishimura, Science 2014