Title: Tensor Network Holography

Date: Jul 28, 2016 02:30 PM

URL: http://pirsa.org/16070076

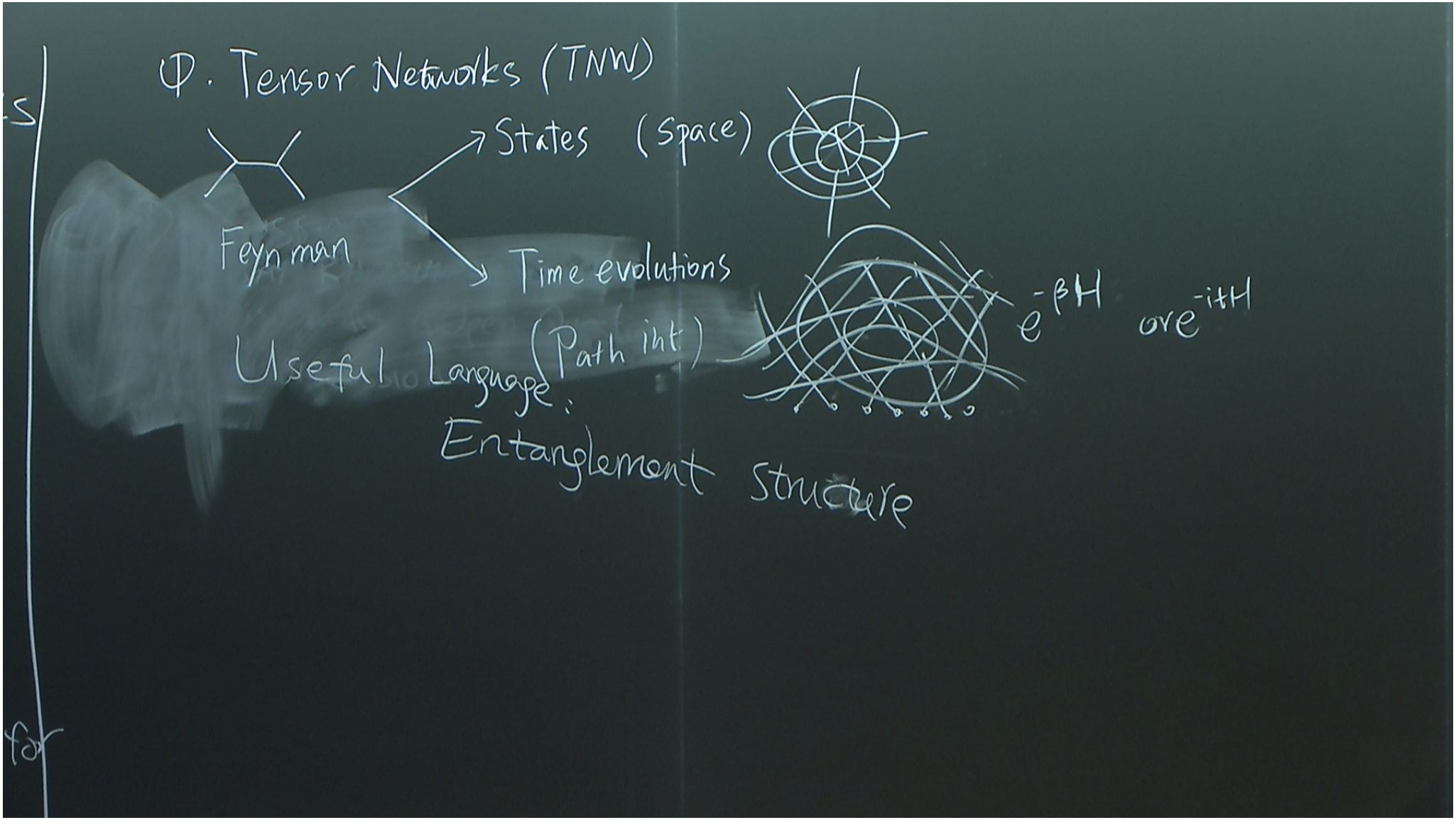
Abstract:

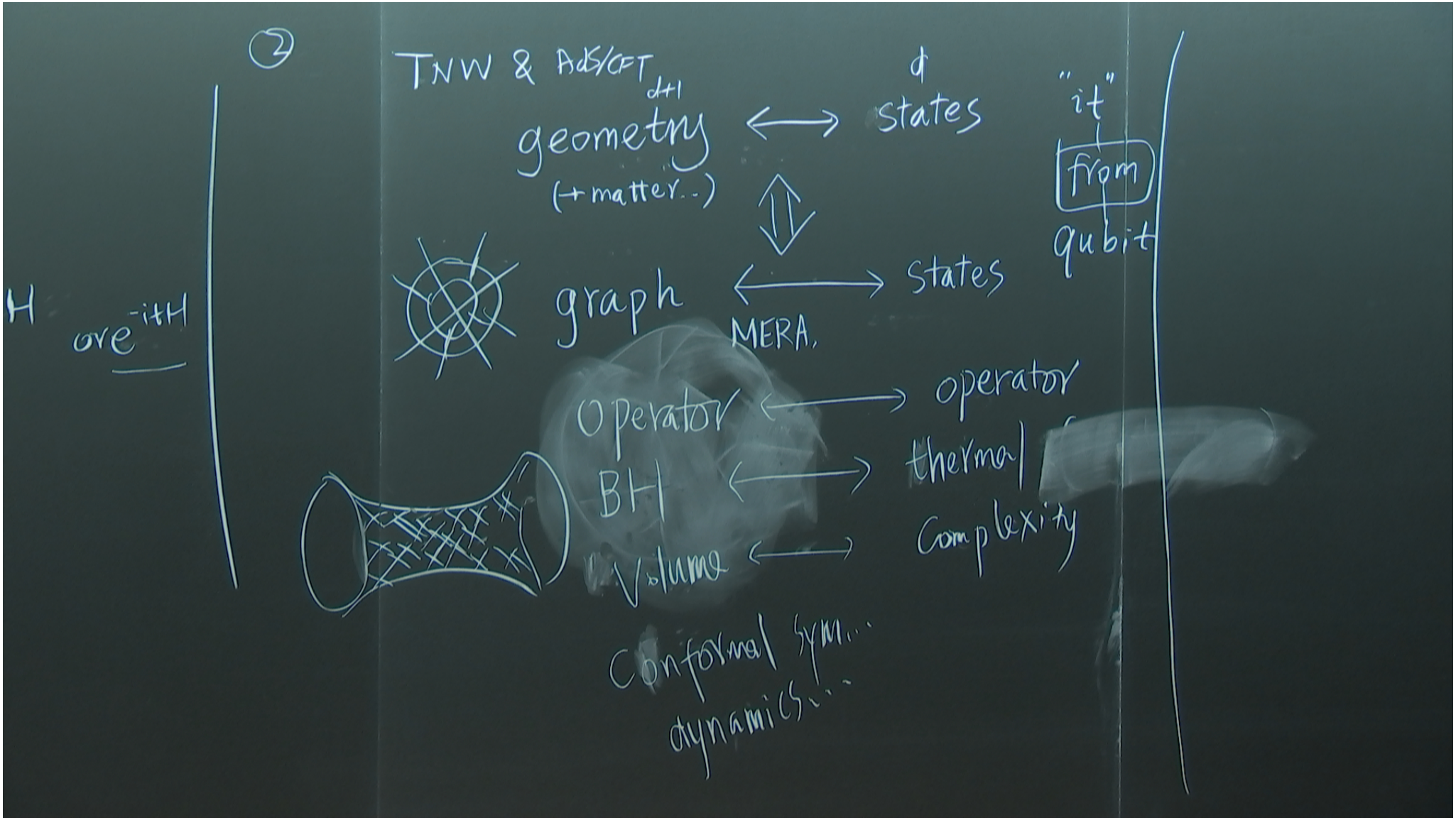
Tensor Networks & Holography

(A) Brief Intro

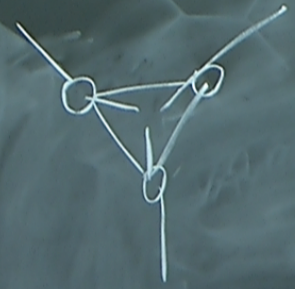
(B) Case Studies
- Xiaoliang Qi
  Highlights)
  Random Tensors & Spacetime
- Brian Swingle
  Black Hole Interiors & Complexity
- Volker Schoz
  tensor networks for CFTs.

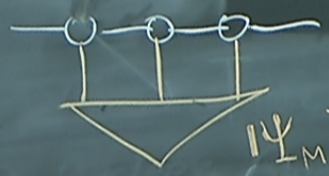
(C) Discussion
- (C.1) Vijay Balasubramanian
  Discontents & Open Questions
- (C.2) Open Discussion

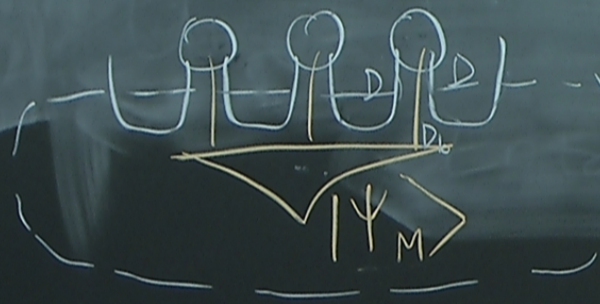

Φ. Tensor Networks (TNW)
States (space)
Feynman
Time evolutions
Useful Language: (Path int)
Entanglement structure
$e^{-\beta H}$
or e^{-itH}


②
TNW & AdS/CFT d+1
geometry ⟷ d states
(+matter..)
graph ⟷ states
MERA.
"it"
from
qubit
H
ove^{-itH}
Operator ⟷ operator
BH ⟷ thermal
Volume ⟷ Complexity
Conformal sym...
dynamics...

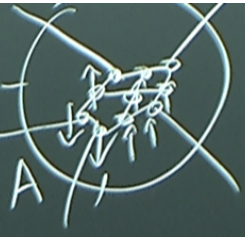
Random TNW.







$$|\Psi_\partial\rangle = \prod_x \langle V_x | \Psi_P \rangle$$



$$\overline{e^{-S_2}} = \sum_{\sigma_x = \pm 1} e^{-S_2[\sigma_x = -1, |\Psi_P\rangle]}$$

① RT + quantum corr.

$\bigcup_D$ $D \to \infty$

$S_2 = \log D\,|\gamma| +$

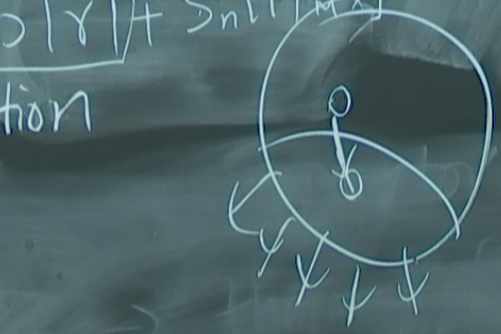
$S_2[|\psi_M\rangle]$

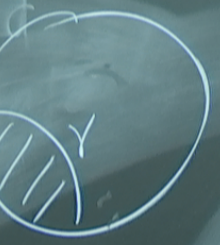
$S_n = \log D\,|\gamma| + S_n[|\psi_M\rangle]$

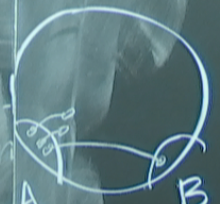
② Bulk reconstruction

Code subspace:



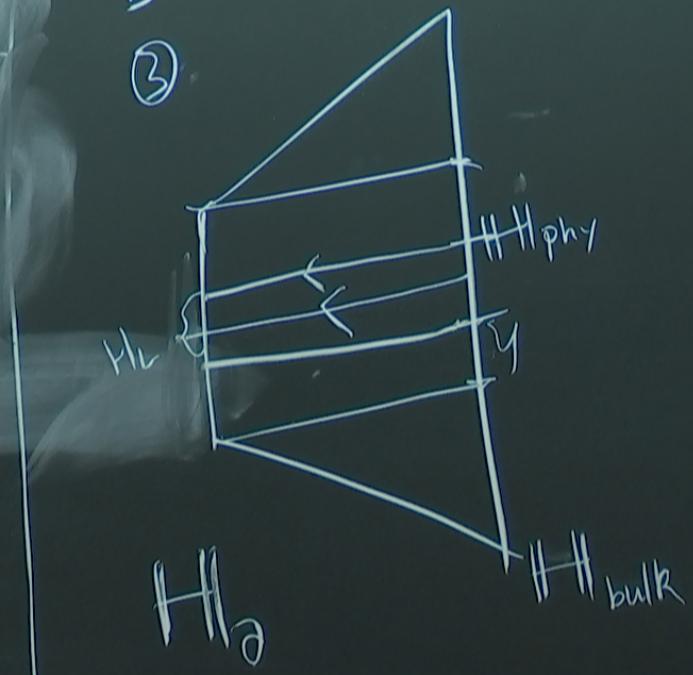






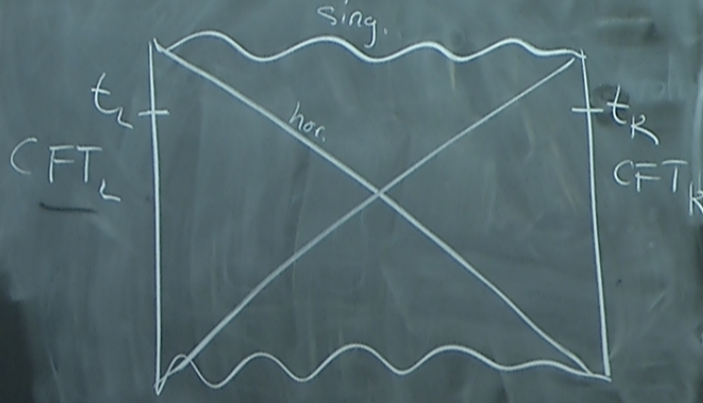
$S_{AB}^n \neq S_A^n + S_B^n$

③



Complexity = Action

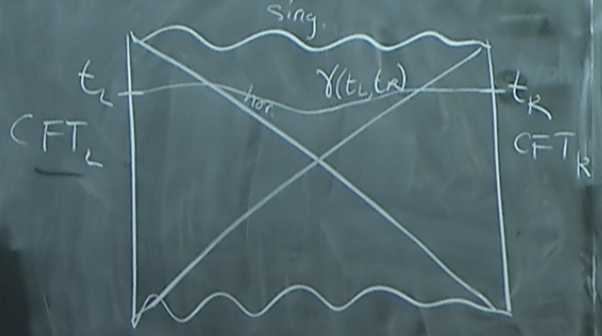
Brown, Roberts, Susskind, Swingle, Zhao



$$|t_L, t_R\rangle = \sum_n \frac{e^{-\beta E_n/2} e^{-iE_n(t_L+t_R)}}{\sqrt{Z}} |E_n\rangle_L |E_n\rangle_R$$

Complexity = Action

Brown, Roberts, Susskind, Swingle, Zhao



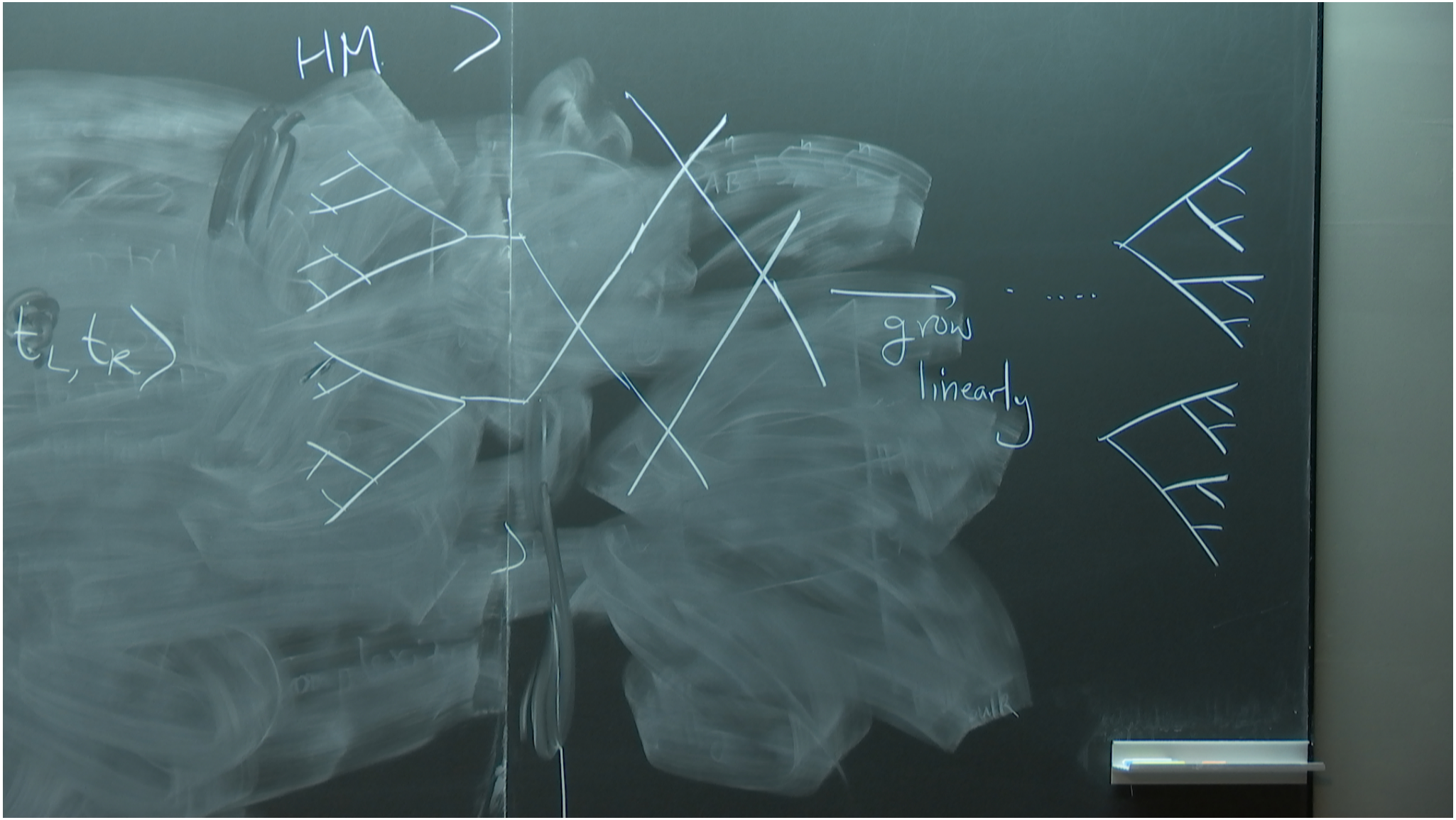
Q: Dual $CFT^{\otimes 2}$ interp?

A: Susskind: Complexity of $|t_L, t_R\rangle$

$$|t_L, t_R\rangle = \sum_n \frac{e^{-\beta E_n/2} e^{-iE_n(t_L+t_R)}}{\sqrt{Z}} |E_n\rangle_L |E_n\rangle_R$$

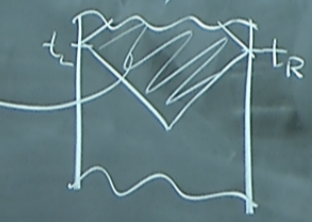
$$\text{length}(\gamma(t_L, t_R)) \approx \#(t_L + t_R) \gg 1$$

Hartman–Maldacena


HM
grow
linearly

Complexity = Action

Brown, Roberts, Susskind, Swingle, Zhao



$$\frac{d\,\text{Action}}{d(t_L+t_R)} = 2M \sim T\,S$$

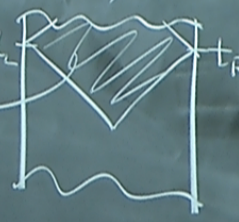
mass of BH

Q: Dual CFT ⊗

A: Susskind: Co

Complexity $\stackrel{?}{=}$ Action

Brown, Roberts, Susskind, Swingle, Zhao



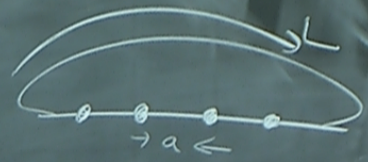
$$\frac{d\,\text{Action}}{d(t_L+t_R)} = 2M \sim T\,S$$

mass of BH

Q: Dual CFT$^{\otimes 2}$,

A: Susskind: Comp

TN model



$\frac{L}{a}$ qubits.

a = UV length

$a \sim \frac{1}{\Lambda}$

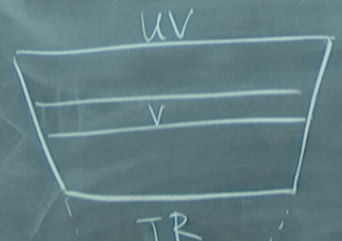
$t=0$, finite T

$\xi = \frac{1}{T}$

$V_{L/2} \to V_L$

$k = \log\left(\frac{\xi}{a}\right) = \log\left(\frac{\Lambda}{T}\right)$

$e^{-it H_{UV}} |TFD\rangle$

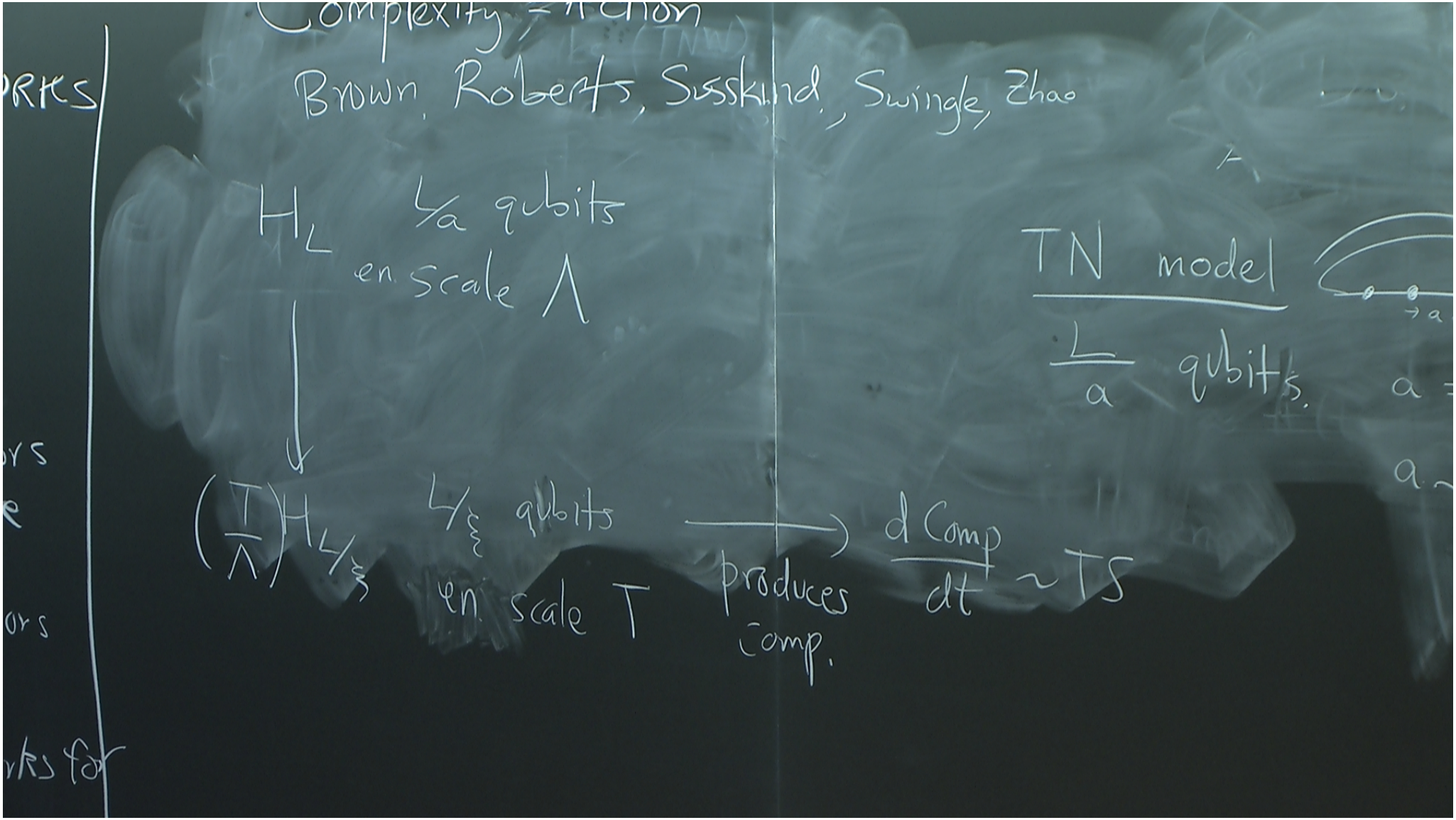


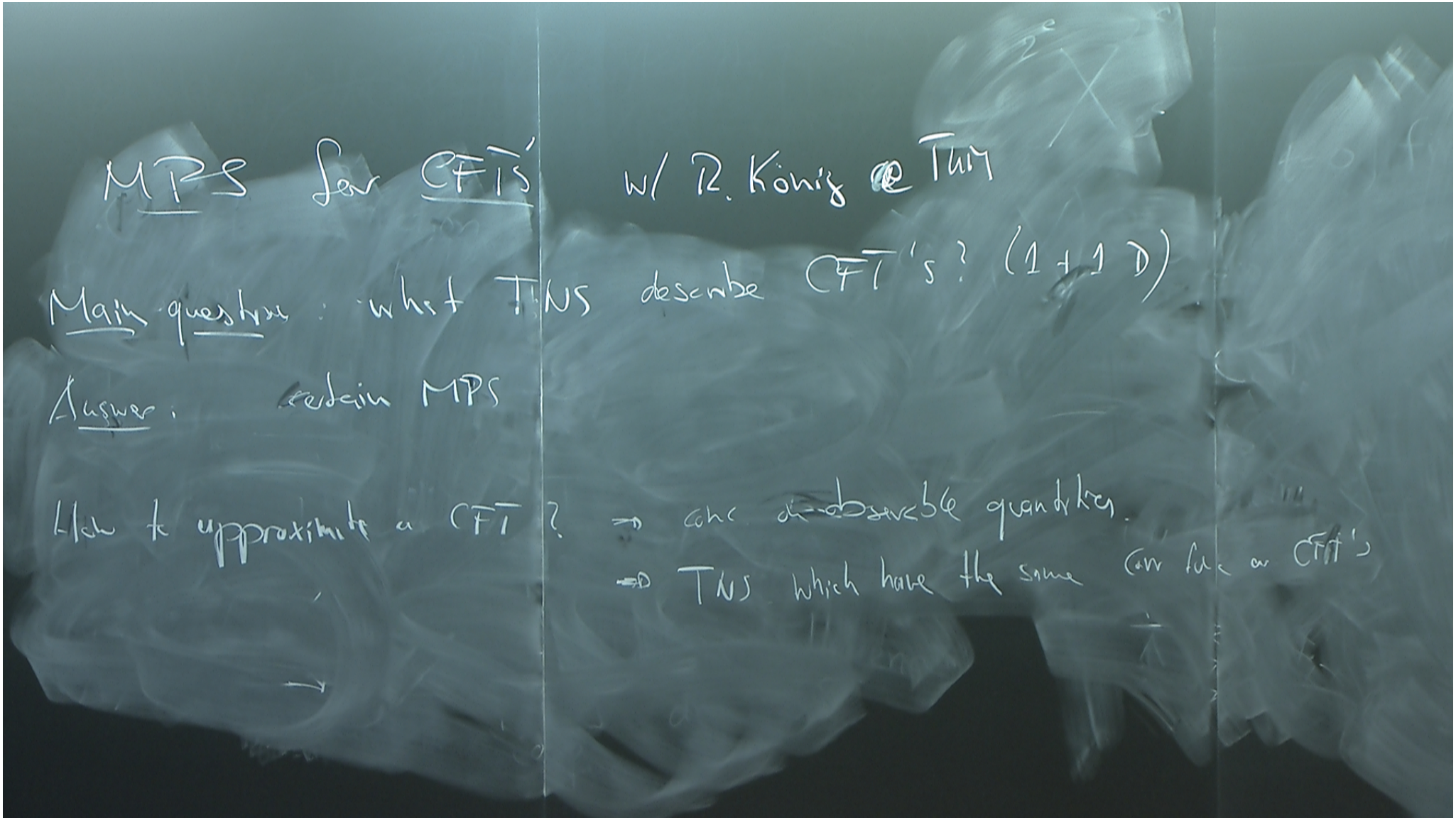
length

$(*)$ $H_L V_{L/2 \to L} \approx V_{L/2 \to L} H_{L/2}$

$2^{-\Delta_H}$

(e.g. MERA)


Complexity = Action
Brown, Roberts, Susskind, Swingle, Zhao
H_L L/a qubits
en scale Λ
TN model
$\frac{L}{a}$ qubits.
$(\frac{I}{\Lambda})H_{L/\xi}$ L/ξ qubits
en scale T
produces comp.
$\frac{d\,Comp}{dt} \sim TS$


MPS for CFTs w/ R. König @ TUM
Main question: what TNS describe CFT's? (1+1 D)
Answer: certain MPS
How to approximate a CFT? → one observable quantity.
→ TNS which have the same corr. fct. as CFT's

$\varphi_{x_1} \cdots \varphi_{x_n}$ primary fields

$$\langle \varphi_1(x_1) \cdots \varphi_n(x_n) \rangle \approx_\varepsilon \langle \hat{\varphi}_1(x_1) \cdots \hat{\varphi}_n(x_n) \rangle_{TNS} \quad (*)$$

for $|x_i - x_j| \geq a$

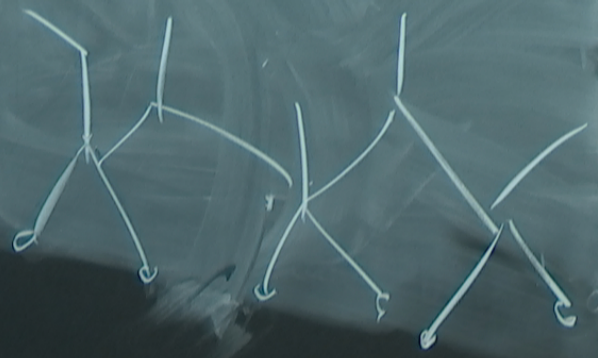
Thm for most CFT's in $1+1$ D, there exists TNS with bond dimension $D \sim \left(\frac{1}{\varepsilon}\right)^{cn}$ for which $(*)$ holds.

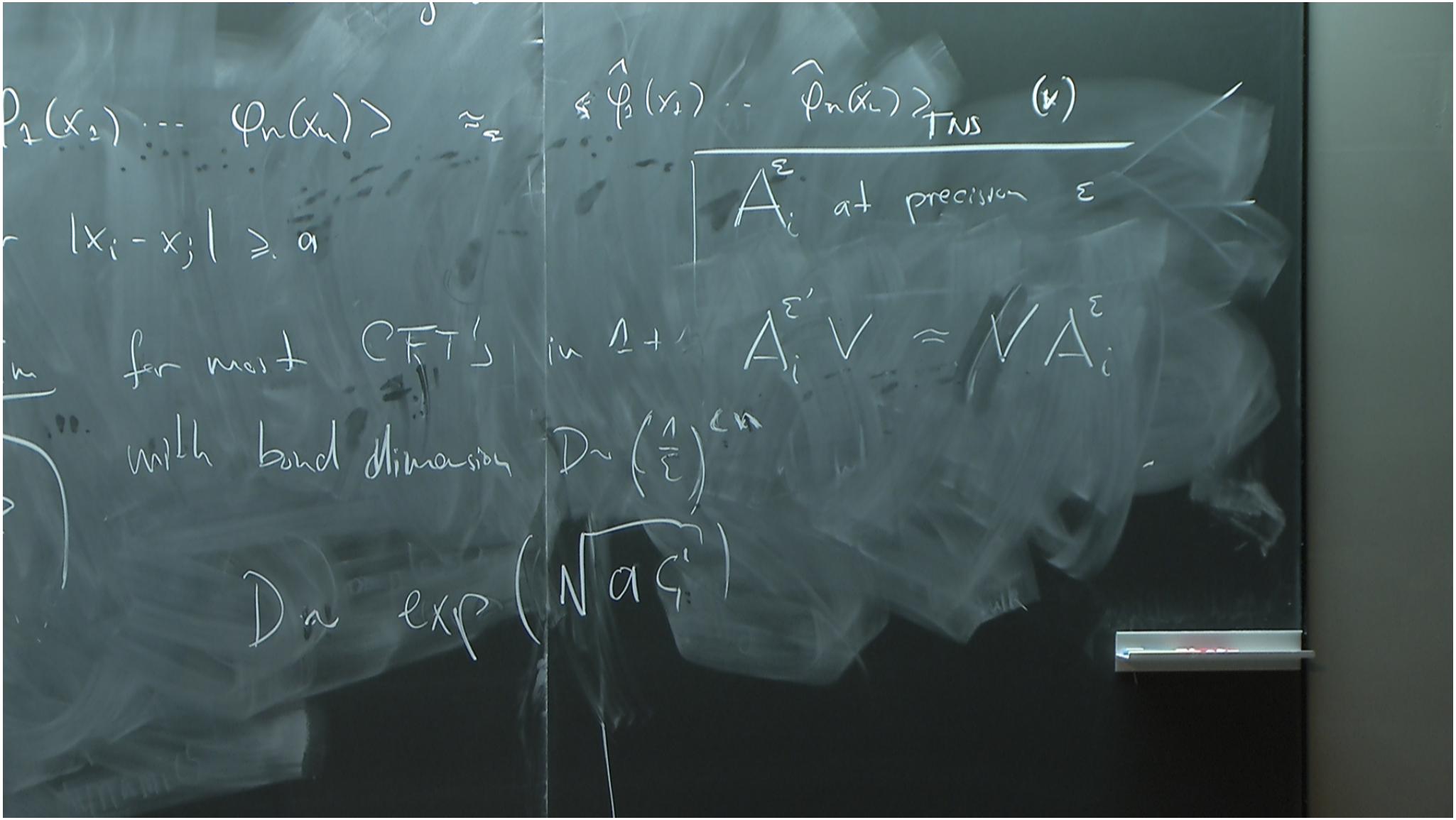
for a CFT's

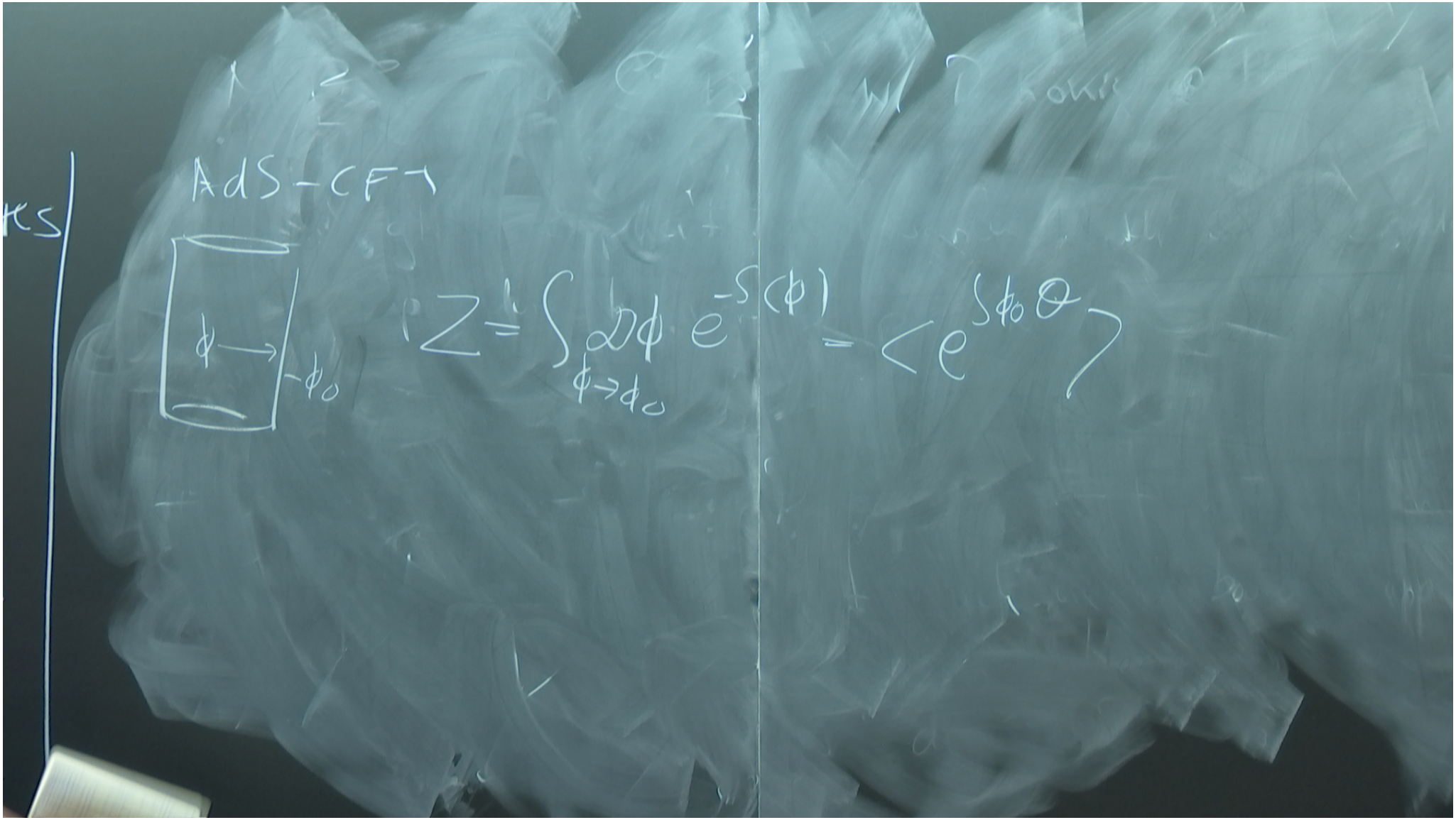
MPS for CFTs w/ R. König @ TUM

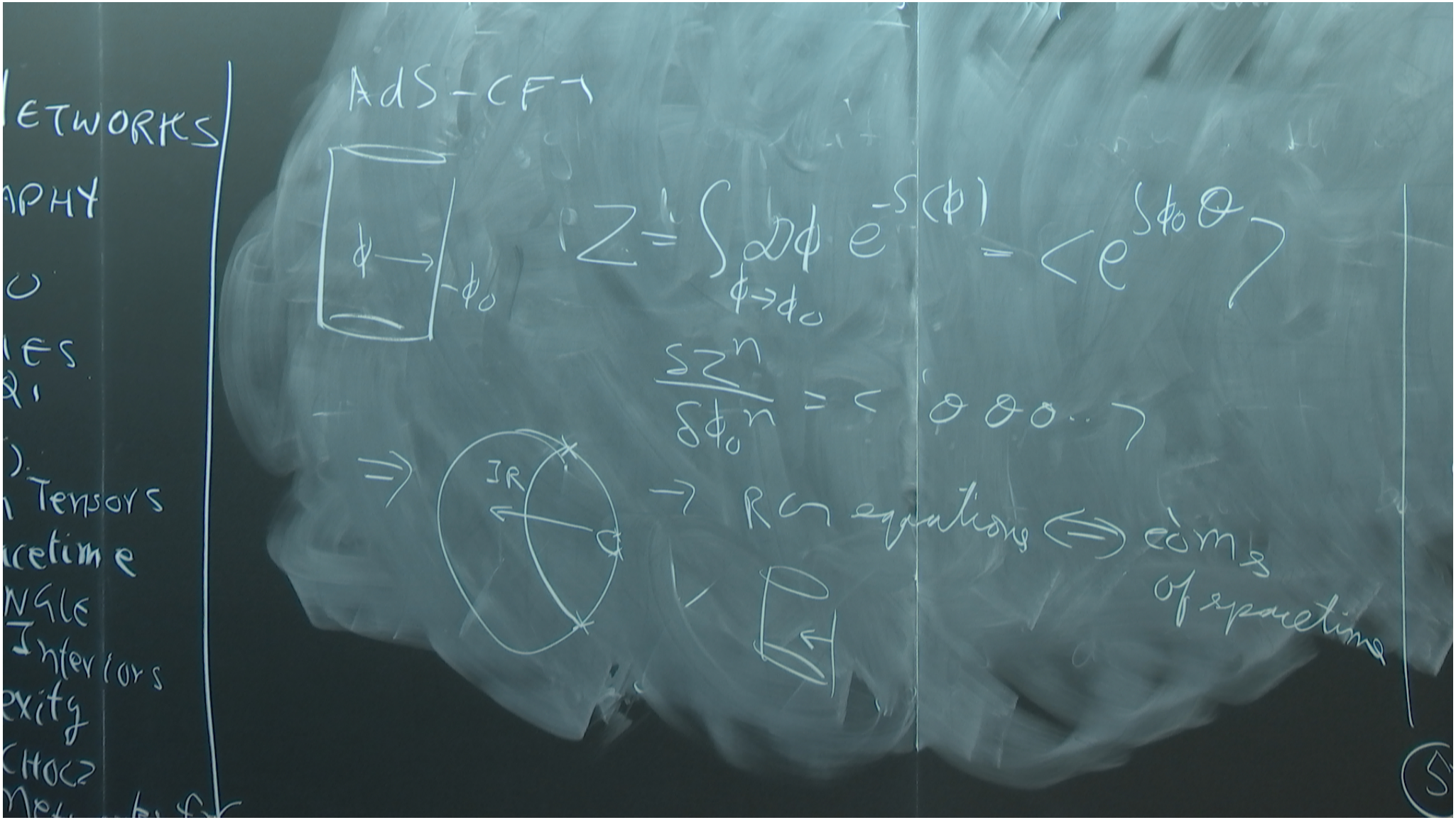
Thm gives explicit construction with universal update procedure to increase precision.

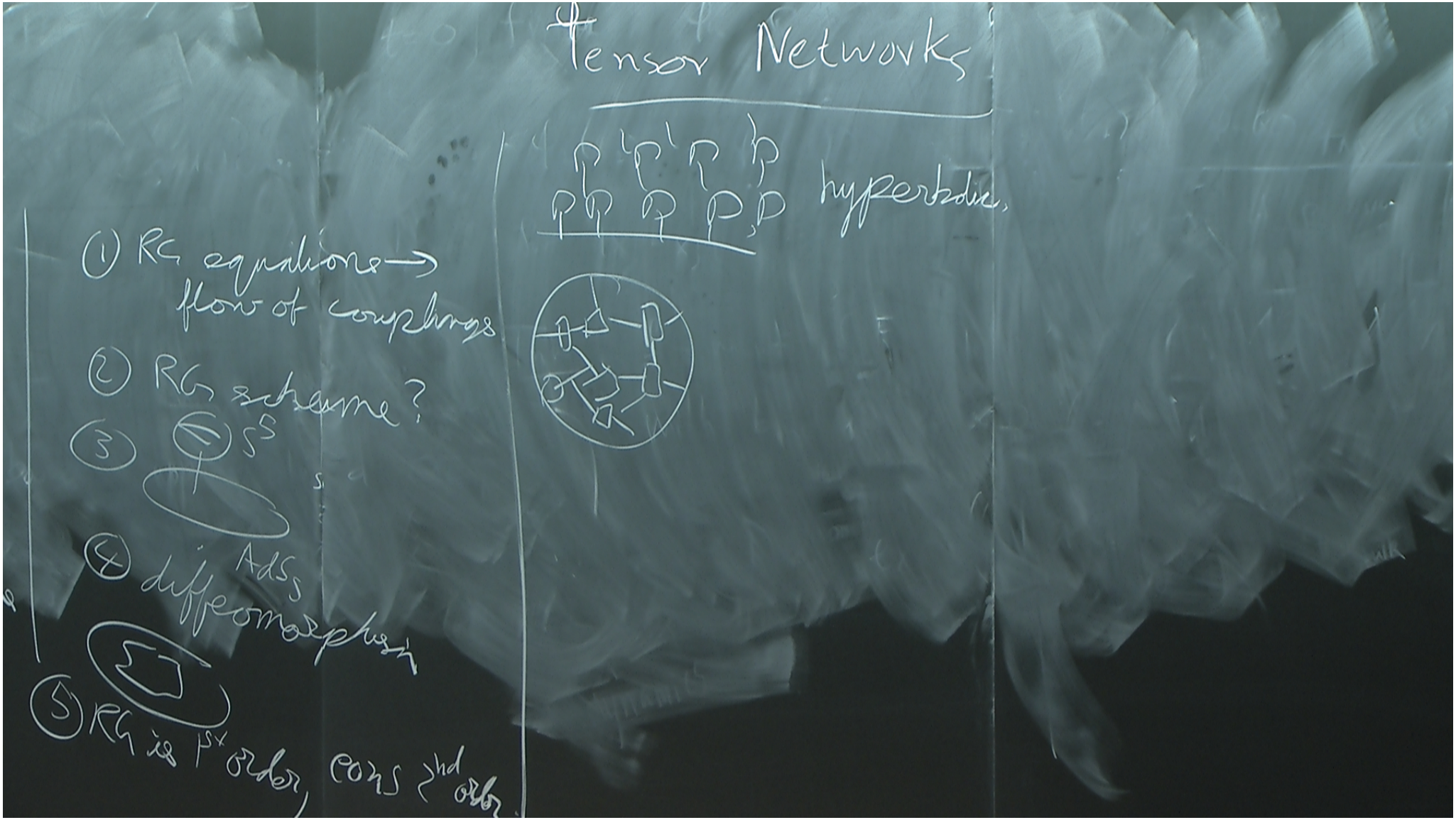
Main open question: Does there exist a TNW with bulk & boundary dof which on the boundary approximates a CFT?




$\varphi_1(x_1) \cdots \varphi_n(x_n)\rangle \approx_\varepsilon \langle \hat{\varphi}_1(x_1) \cdots \hat{\varphi}_n(x_n)\rangle_{TNS}$ (*)
$|x_i - x_j| \geq a$
for most CFT's in 1+1
with bond dimension $D \sim \left(\frac{1}{\varepsilon}\right)^{cn}$
A_i^ε at precision ε
$A_i^{\varepsilon'} V \approx V A_i^\varepsilon$
$D \sim \exp\left(N \sqrt{a \zeta_i}\right)$

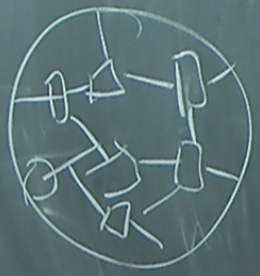

AdS-CFT
$\phi \to \phi_0$
$Z = \int_{\phi \to \phi_0} \mathcal{D}\phi\, e^{-S(\phi)} = \langle e^{\int \phi_0 \mathcal{O}} \rangle$


ETWORKS
APHY
Tensors
acetime
NGLE
Interiors
exity
CHOC?
AdS-CFT
$\phi \to \phi_0$
$Z = \int_{\phi \to \phi_0} \mathcal{D}\phi\, e^{-S(\phi)} = \langle e^{\int \phi_0 \mathcal{O}} \rangle$
$\frac{\delta Z^n}{\delta \phi_0^n} = \langle \mathcal{O}\mathcal{O}\mathcal{O}\ldots \rangle$
IR
RG equations $\Leftrightarrow$ eoms of spacetime


Tensor Networks
hyperbolic
① RG equations → flow of couplings
② RG scheme?
③
④ AdS/CFT
diffeomorphism
⑤ RG is 1st order, EOMs 2nd order

Tensor Networks

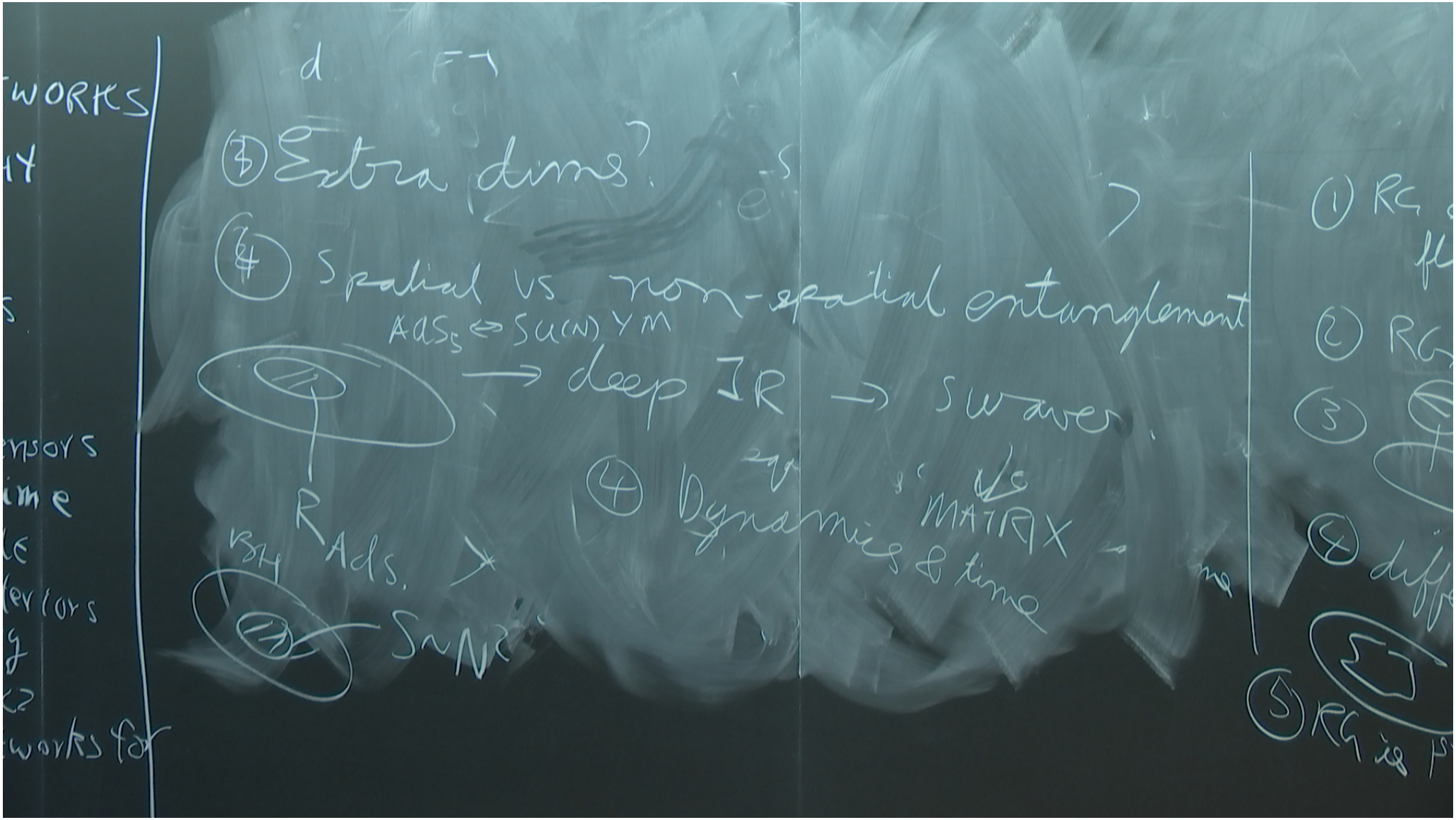
hyperbolic



RG for states vs RG for couplings?

① Coms
2nd { Values of fields → g
$\partial_x \phi$ → ⟨0⟩

② RG scheme
↳ which network


WORKS
Extra dims?
Spatial vs non-spatial entanglement
AdS5 ⇔ SU(N) YM
deep IR → sw
Dynamics & time
MATRIX
RAds.
SM
RG