HOLOGRAPHIC RELAXATION OF FINITE SIZE CLOSED SYSTEMS

Esperanza Lopez, IFT-UAM/CSIC

with Javier Abajo-Arrastia, Emilia da Silva, Javier Mas & Alexandre Serantes, arXiv:1403.2632

OUT OF EQUILIBRIUM DYNAMICS OF ISOLATED QUANTUM SYSTEMS

Macroscopic system

On general grounds: expected a fast approach to a stationary state

at the macroscopic level appears as thermal equilibrium

Not always the case:

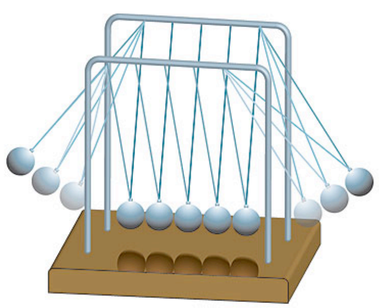
Integrable systems conserved charges prevent thermal equilibration

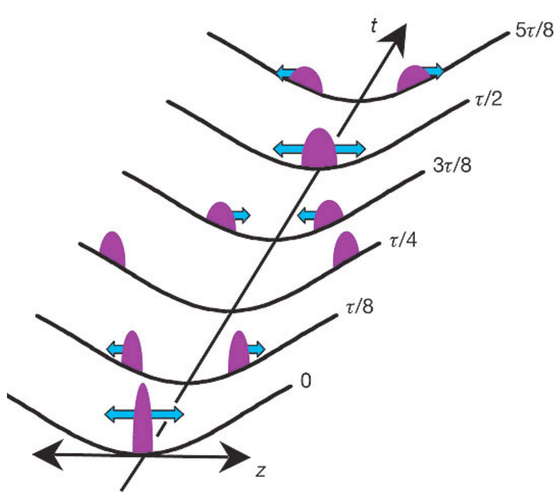
Even in presence of (small) integrability breaking parameters

OUT OF EQUILIBRIUM DYNAMICS OF ISOLATED QUANTUM SYSTEMS

Ex: quantum Newton's cradle

(Kinoshita,Wegner,Weis, Nature 2006)

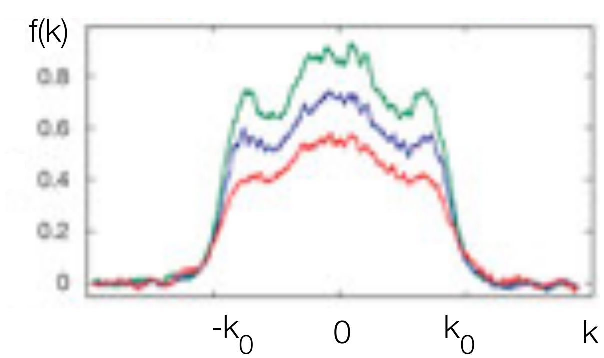




atoms in a 1d anharmonic trap

- initial state partially reconstructs — revivals
- (quasi) stationary state keeps memory of initial conditions

pre-thermalization plateau



- thermalization only after a long time scale

holography

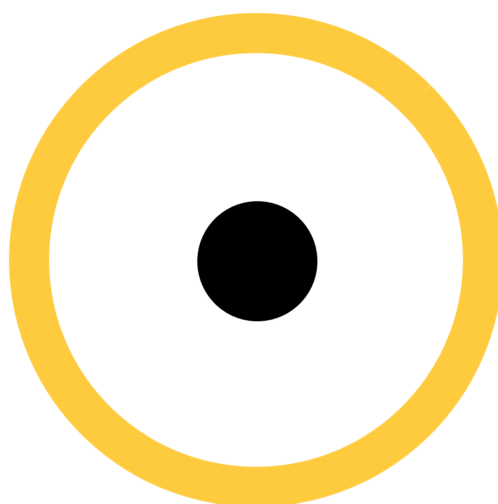
FT thermalization ⟺ gravitational collapse

GRAVITATIONAL COLLAPSE

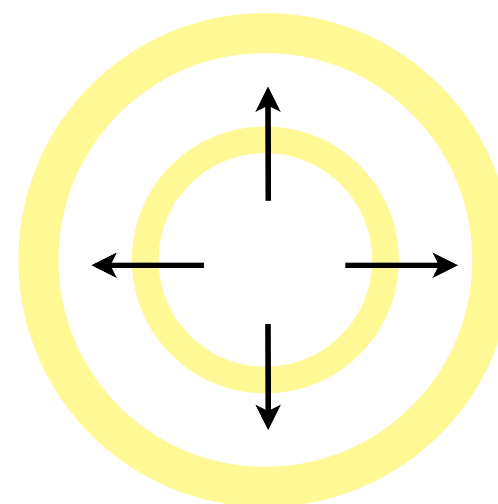
asymptotically flat spacetime + massless spherical scalar shell

(Choptuik, 1993)

above M_{th}

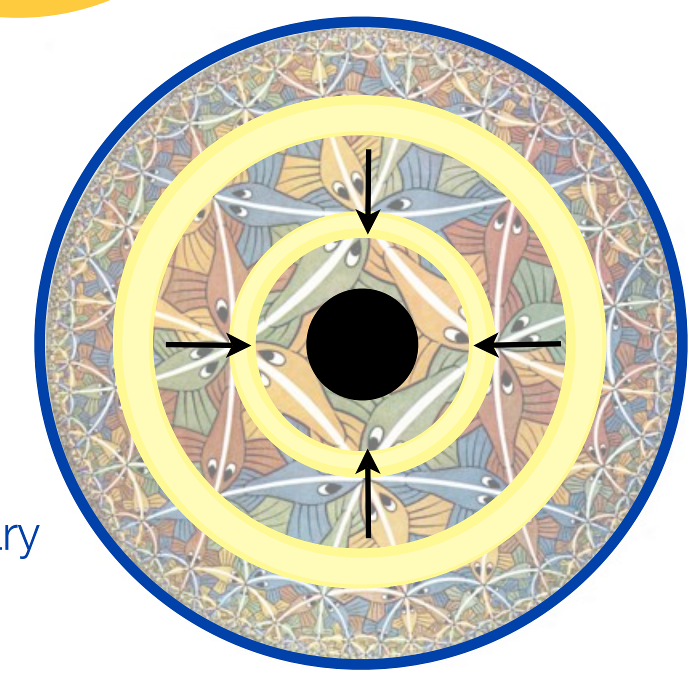


below M_{th}



asymptotically AdS

(Bizon,Rostworowski, 2011)



reflecting boundary

narrow pulses: always collapse

period of a bounce: $\simeq \pi$

broad pulses: might not form a horizon

(Buchel,Liebling,Lehener, 2013)

OUTLINE

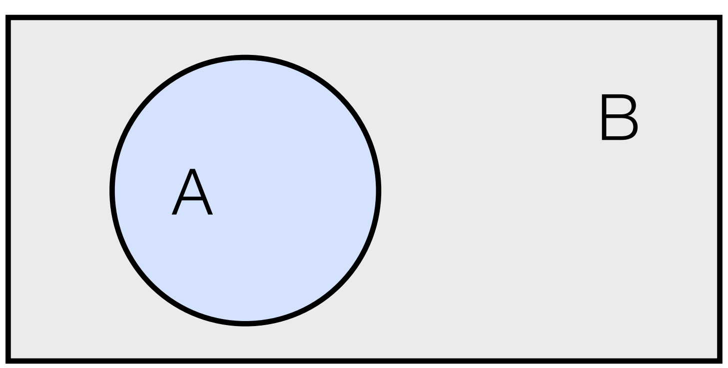
bouncing geometries ⇦ holographic dictionary ⇨ out of equilibrium dynamics of strongly coupled FTs

revivals

probe observable: entanglement entropy

$$S_A = -\mathrm{Tr}_A(\rho_A \ln \rho_A)$$

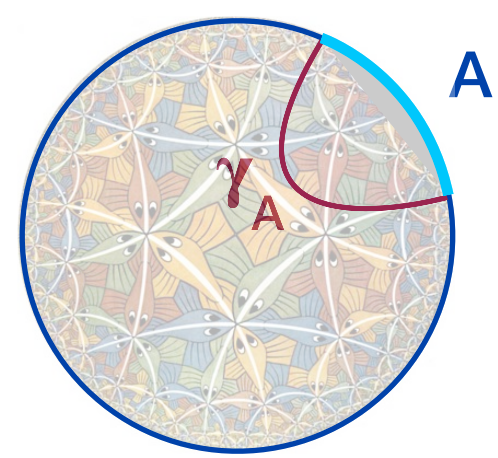
measure of quantum correlations between A and B



$$\rho_A = \mathrm{Tr}_B \rho$$

HEE: $$S_A = \frac{\mathrm{Area}(\gamma_A)}{4G_N}$$

(Ryu,Takayanagi 2006;
Hubeny,Rangamani,Takayanagi 2007)



QUANTUM QUENCHES

unitary evolution

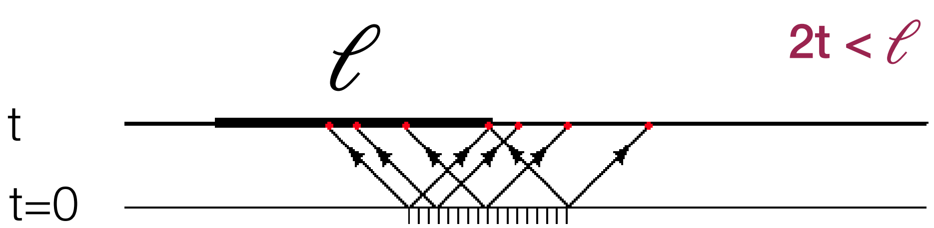
$$H_0 \to H$$

$$|\Psi_0\rangle \to |\Psi_0(t)\rangle$$

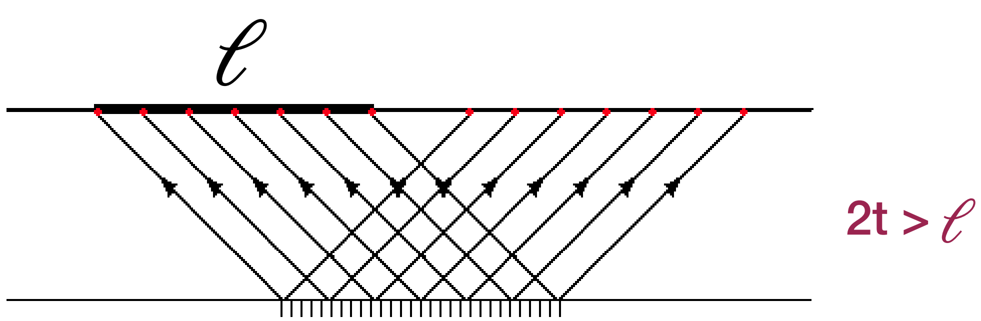
global quench

2d CFT after a massive to critical quench:

(Cardy,Calabrese 2005)



$S(t,l) \propto 2t$



no entangled dof are contained in the interval

$S(t,l) \propto l$

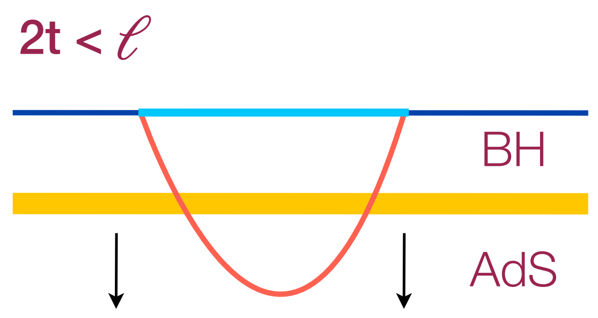
initial state: correlations stronger among nearest neighbours

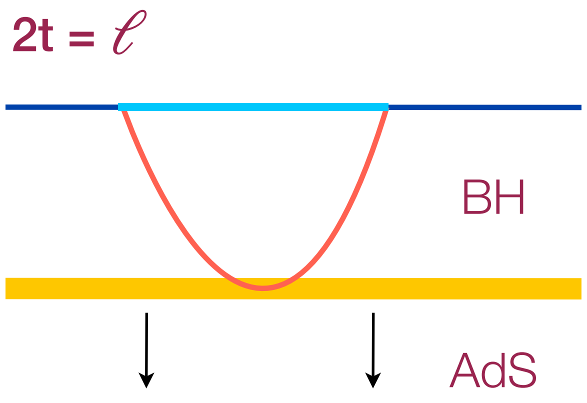
late time: the system appears thermal on ever larger regions

HOLOGRAPHIC MODEL

AdS3 null dust thermalization model:

(Abajo-Arrastia,Aparicio,EL 2010;
Balasubramanian et al 2010)





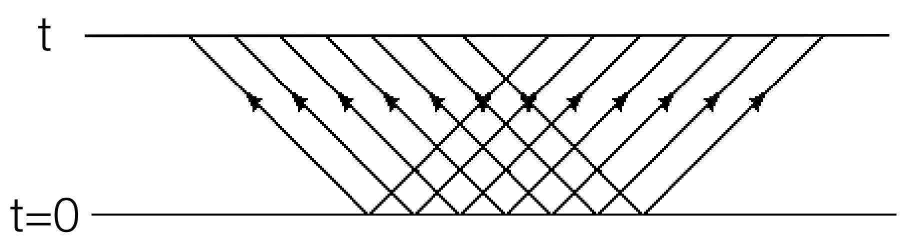
radial position of the pulse
appears to capture the
typical separation of entangled dof

close to the boundary:

entanglement mainly over neighboring dof

infall of the pulse:

excitations fly apart at the speed of light



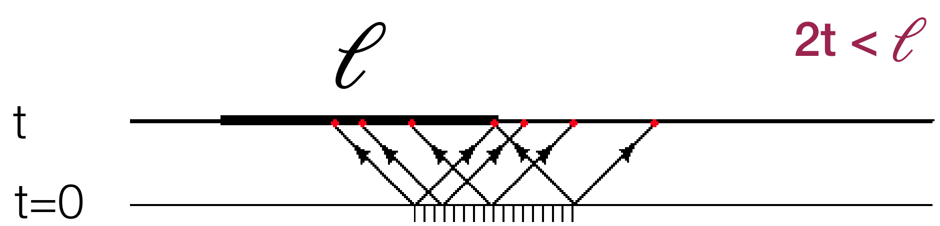
holographic model for a local quench

(Nozaki,Numasawa,Takayanagi,2013)

DEPHASING AND SELF-RECONSTRUCTION

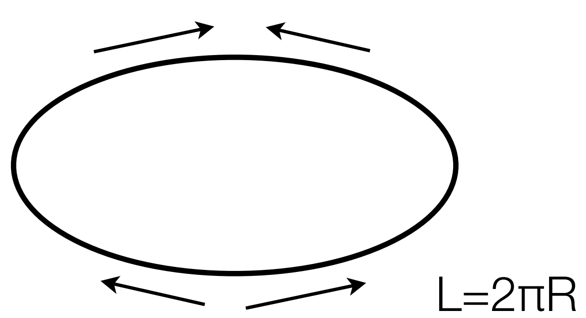
dephasing: loss of quantum coherence

(macroscopic observables)



no global dephasing for finite t

compact space: excitations flying apart reunite again



propagation time: $t_0 = \frac{L}{2v}$

different scenarios depending on t_0 / t_{dph}

DEPHASING AND SELF-RECONSTRUCTION

- free system with linear dispersion relation

initial state reconstructs with period t_0 $O(t)=O(t+t_0)$ $t_{dph} = \infty$ never equilibrates

revivals

holographic dual? black hole evaporation/formation at weak coupling

(Takayanagi,Ugajin 2010)

- free system with non-linear dispersion relation

ex: periodic chain of coupled harmonic oscillators $\omega_p \propto 2\sin\frac{p}{2}$

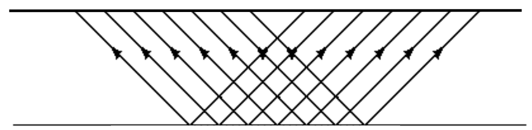
low momenta initial state $t_{dph} \propto 1/\omega$

- revivals before dephasing
- afterwards stationary (but non-thermal) state

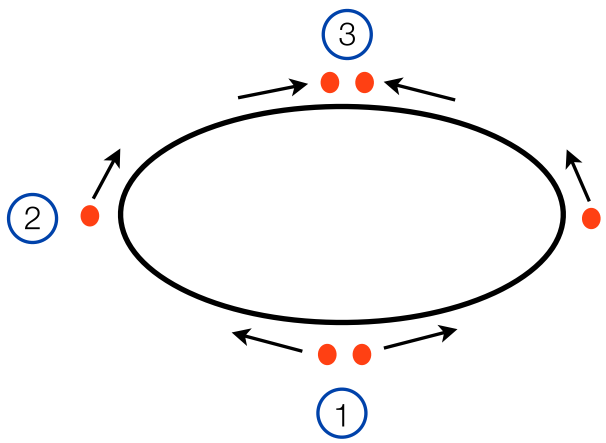
DEPHASING AND SELF-RECONSTRUCTION

* interacting system

1 → 2 as in non-compact case



2 → 3 on general grounds, initial state does not reconstruct



no revivals expected

proposal: although not generic, revivals might appear also at strong coupling

bouncing geometries

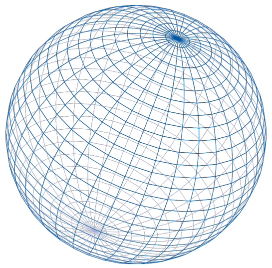
DUAL INTERPRETATION OF THE BOUNCES

initial state partially reconstructs
several times before equilibration

$t_{dph} > t_0$

global AdS_4 ⟷ CFT_3 in S^2

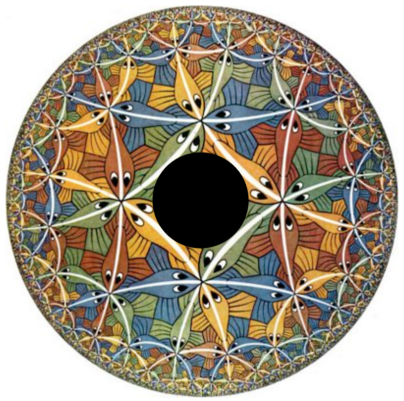
$$t_0 = \frac{L}{2v} = \pi \simeq \text{periodicity of the bounces}$$



R=1

bounces only for $M < M_{\text{large BH}}$

small FT energy density



small BH have negative specific heat

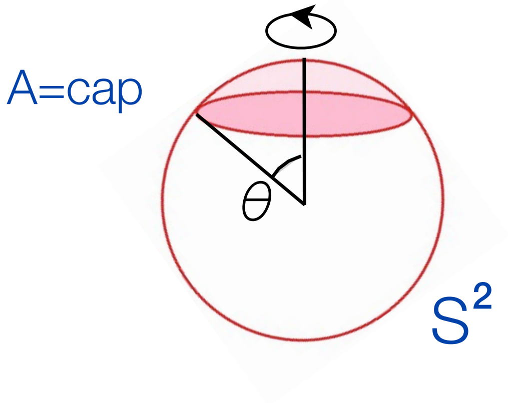
Hawking radiation suppressed at small G_N

preferred states at fixed M

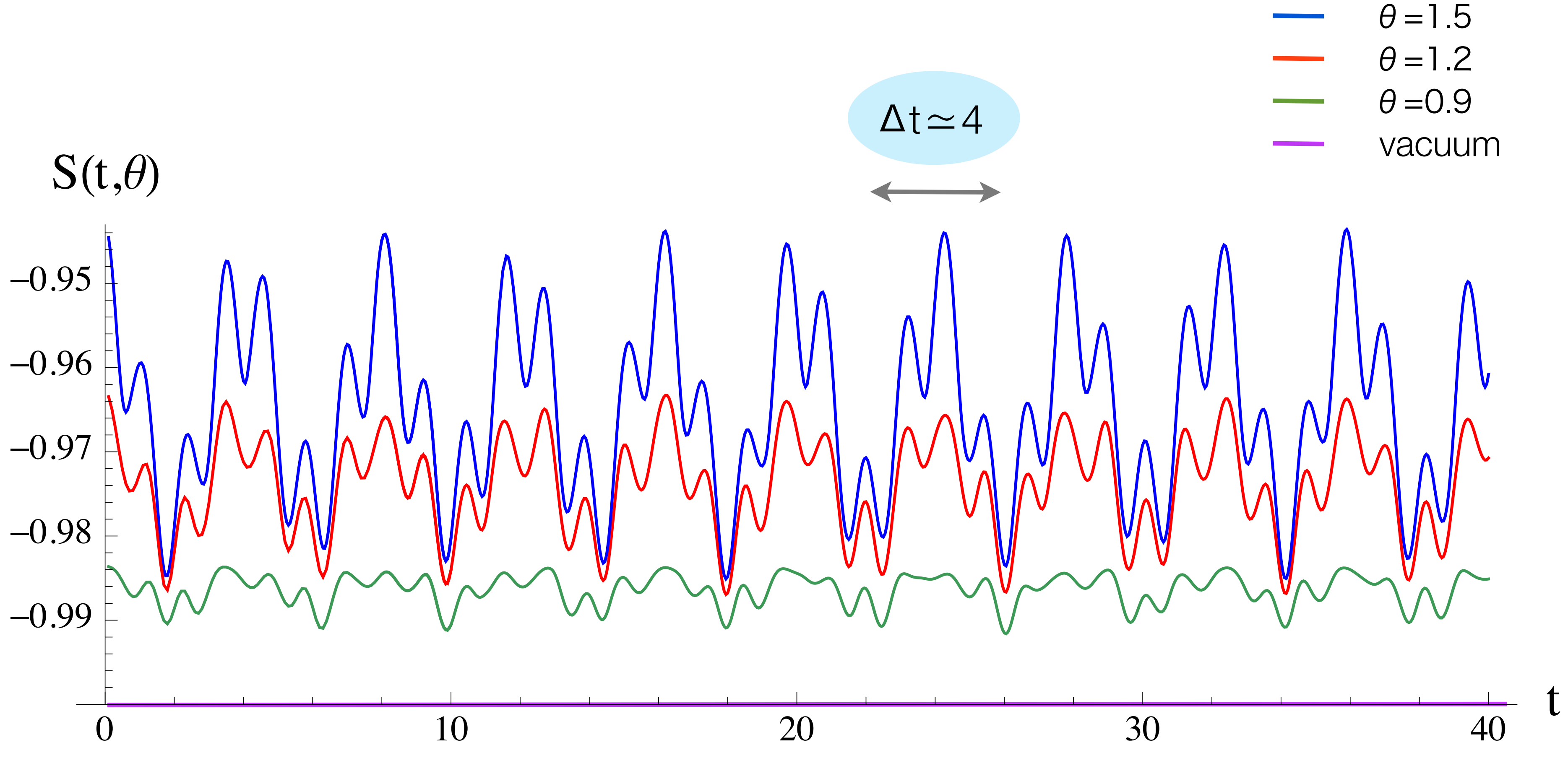
(Dias,Horowitz,Santos, 2002)

ENTANGLEMENT ENTROPY

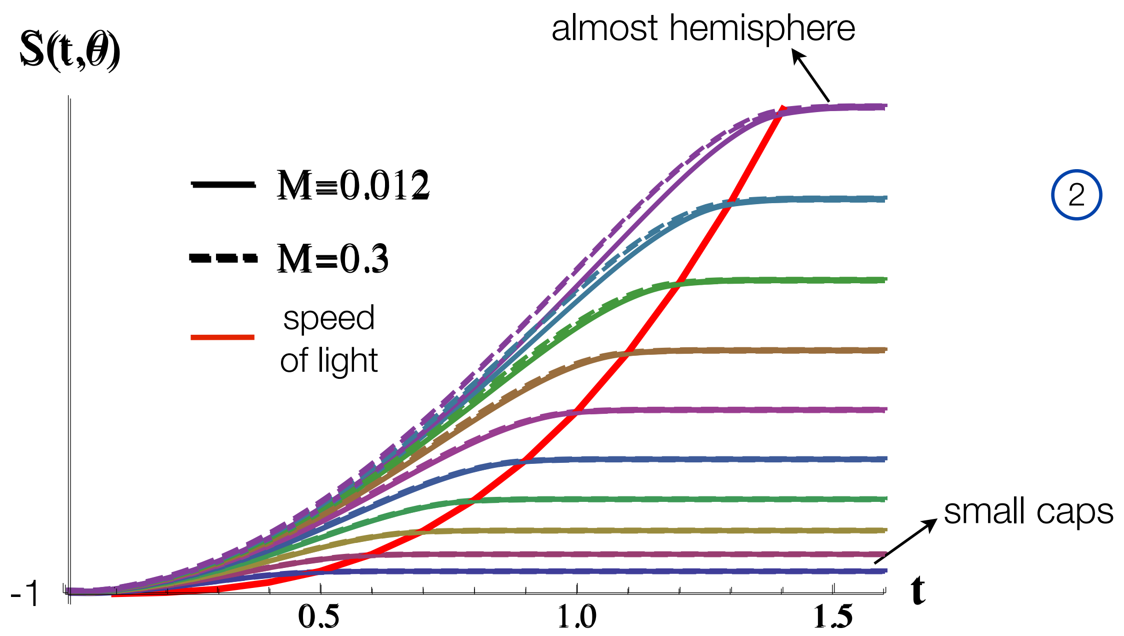
entanglement entropy: $S_A = -\mathrm{Tr}_A(\rho_A \ln \rho_A)$

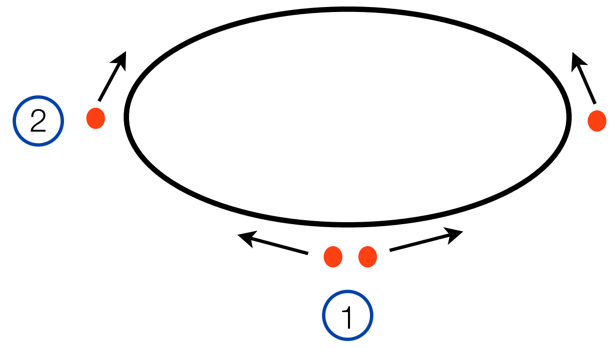


bouncing processes: **oscillating EE**



ENTANGLEMENT ENTROPY:
EARLY TIME DYNAMICS





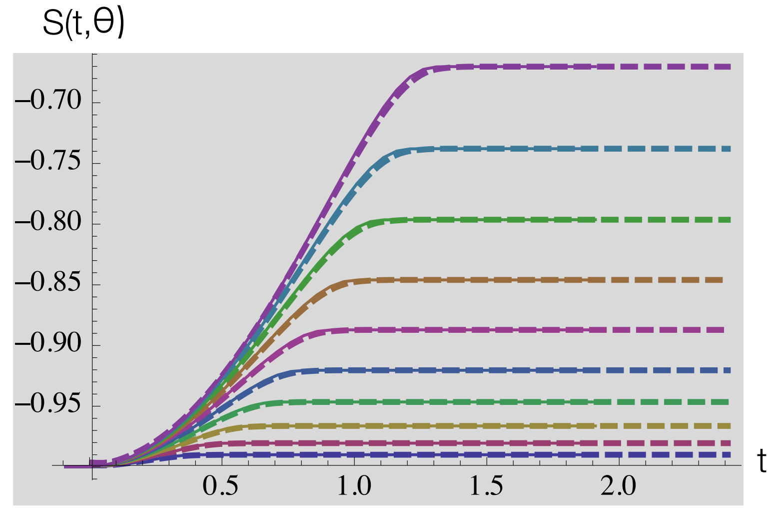
1 → 2

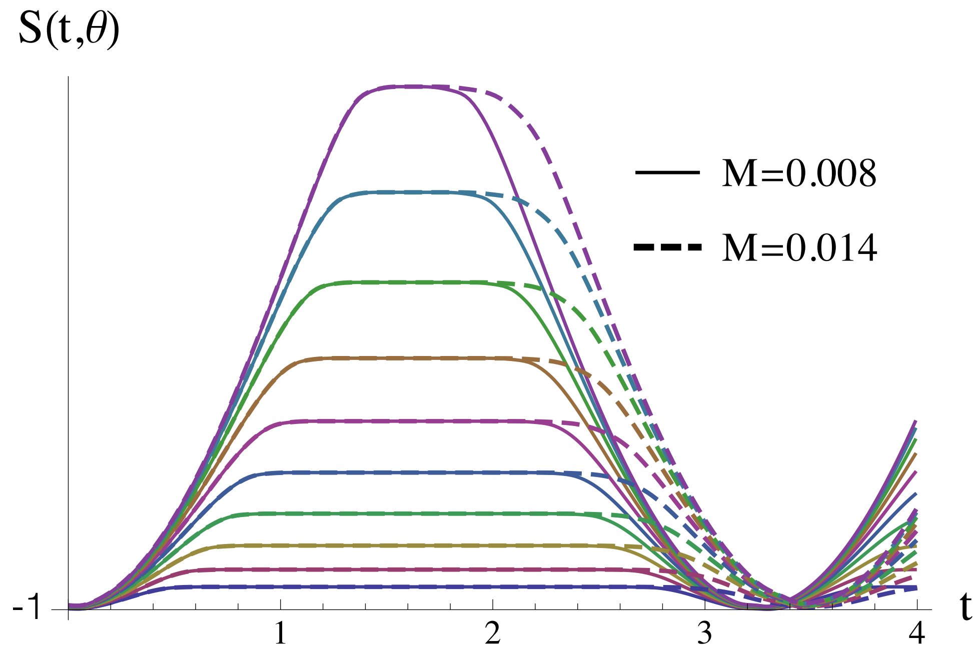
as in non-compact case

independent of M

null dust versus scalar shell of the same M

no difference



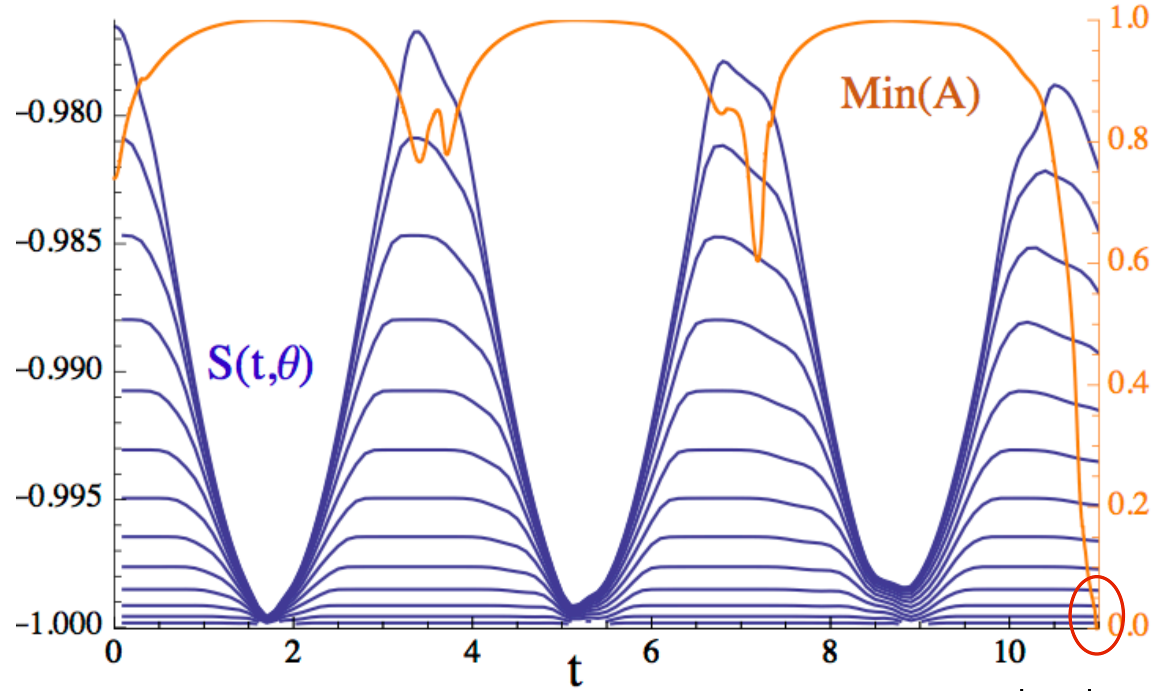


2 interactions may induce a phase shift delaying reconstruction

this effect grows with M

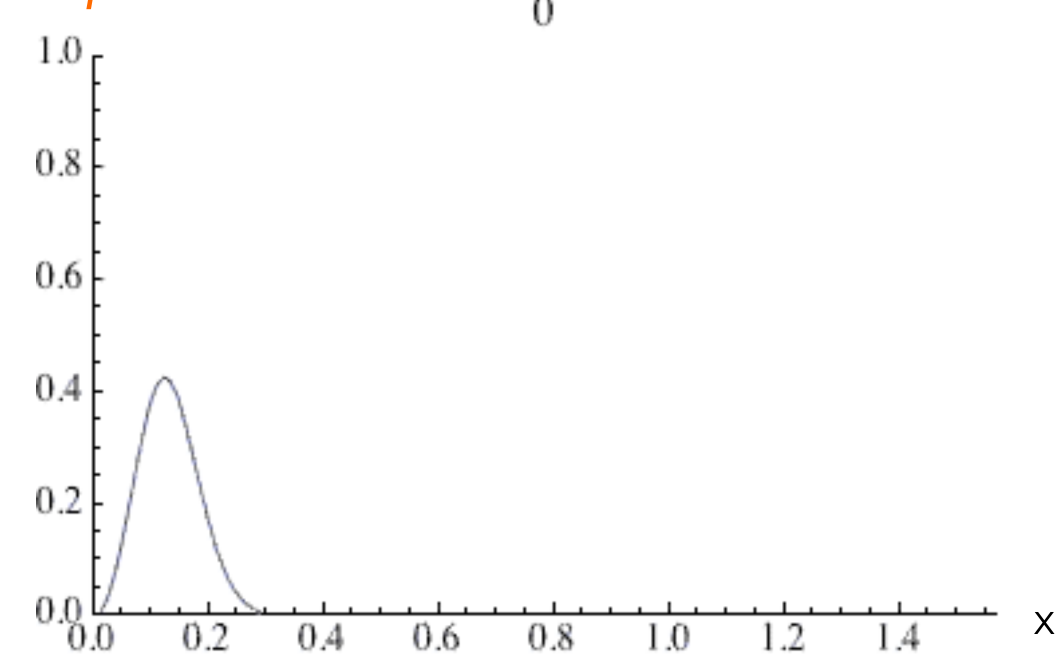
ENTANGLEMENT ENTROPY: NARROW PULSES

$\Delta t \simeq 3.5$



horizon forms

blackening factor ⟶ A(t,x)



$\rho(t,x)$: energy distribution function

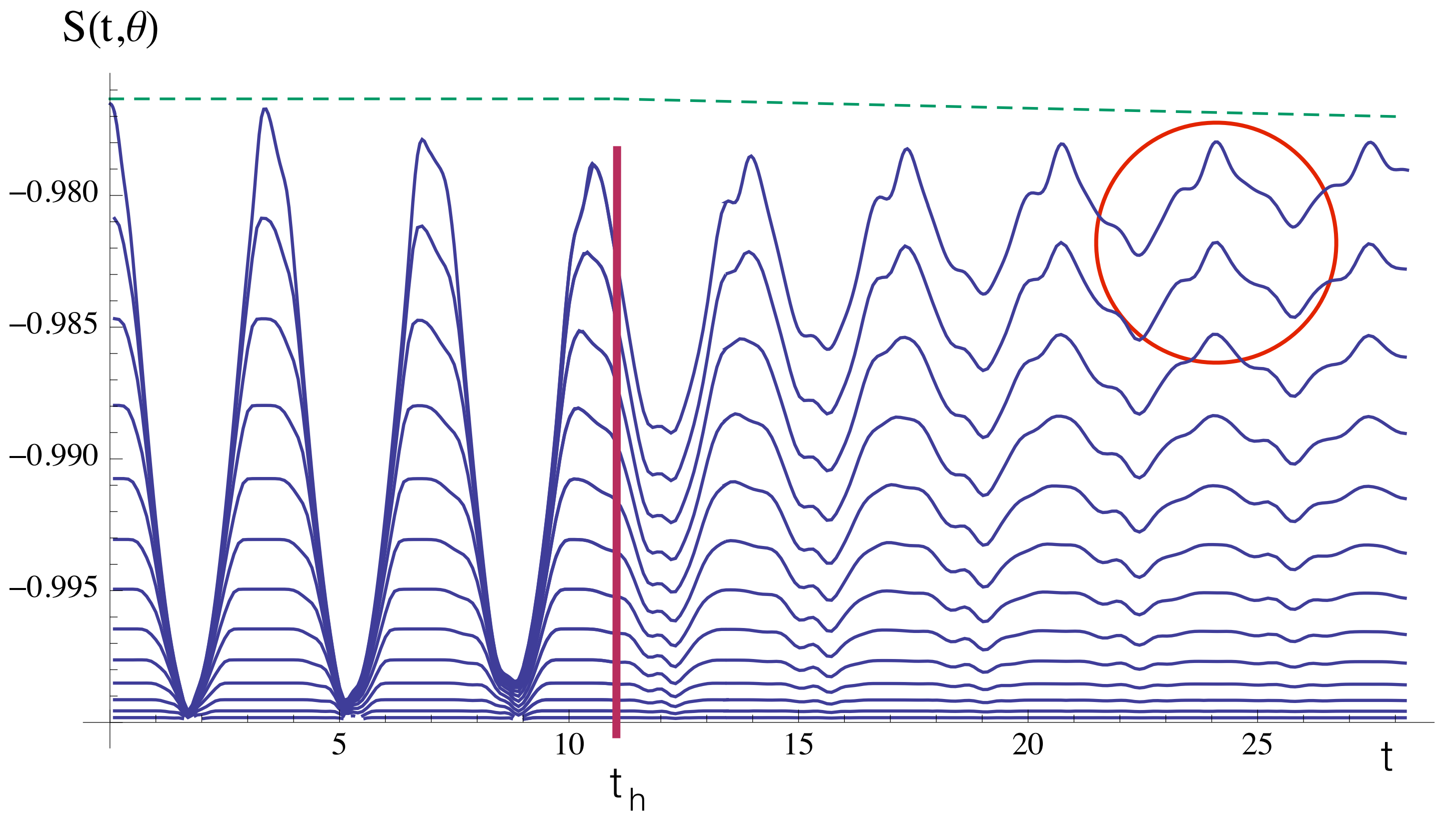
x=0: origin
x=π/2: boundary

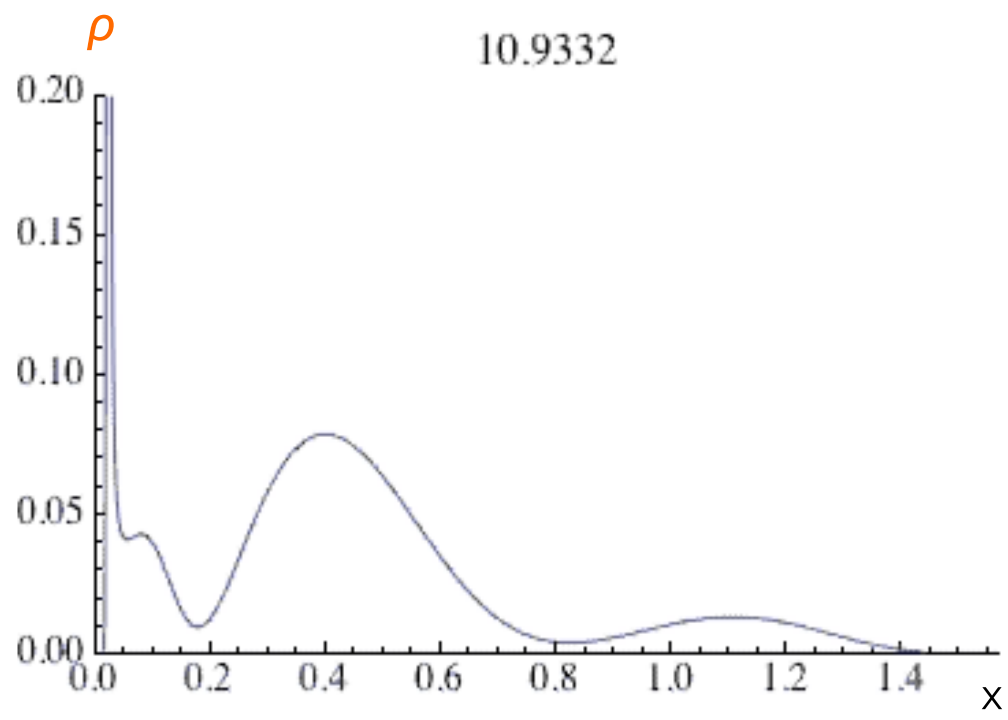
maxima of the EE decrease

weak turbulence:

a fraction of the pulse sharpens
the rest disperses

ENTANGLEMENT ENTROPY: POST-HORIZON EVOLUTION





stepwise relaxation

the EE is smooth across horizon formation

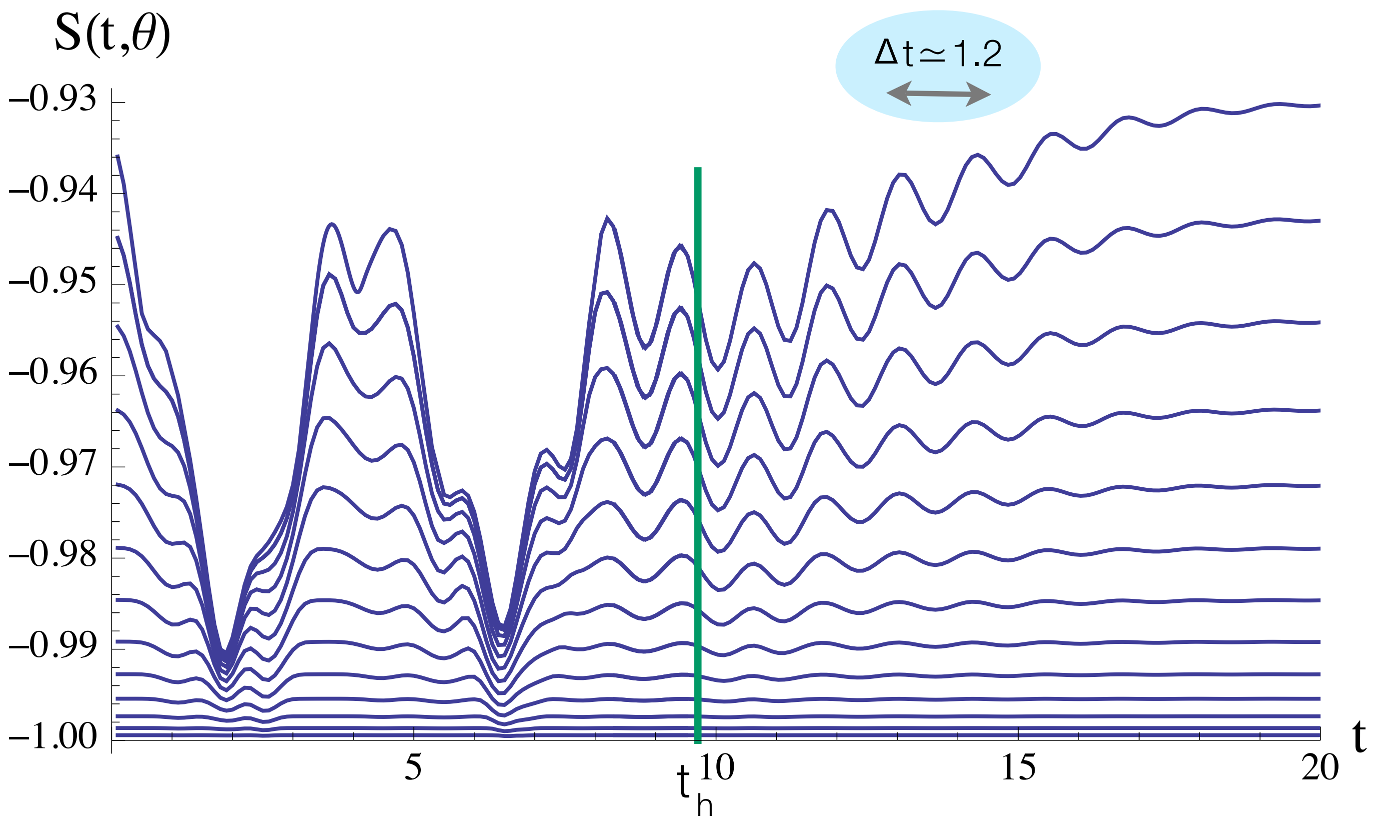
the growing horizon leads to damped oscillations

emergence of an additional modulation with $\Delta t \simeq \pi/3$

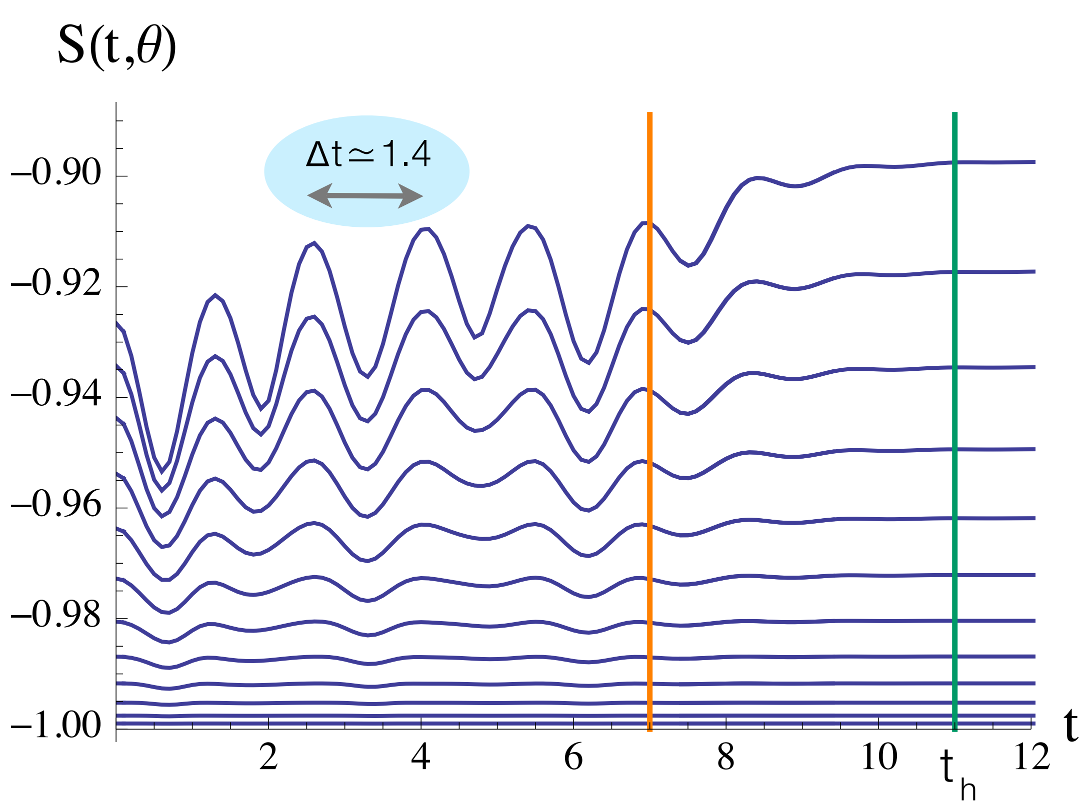
lowest oscillon frequency

ENTANGLEMENT ENTROPY: BROAD PULSES

intermedium broadness



maximal broadness



pre-horizon: radial localization

post-horizon: radially delocalized

radially delocalized

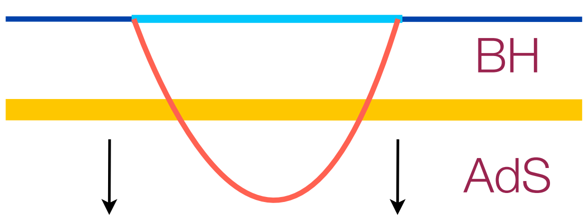
delocalized dynamics: efficient EE growth

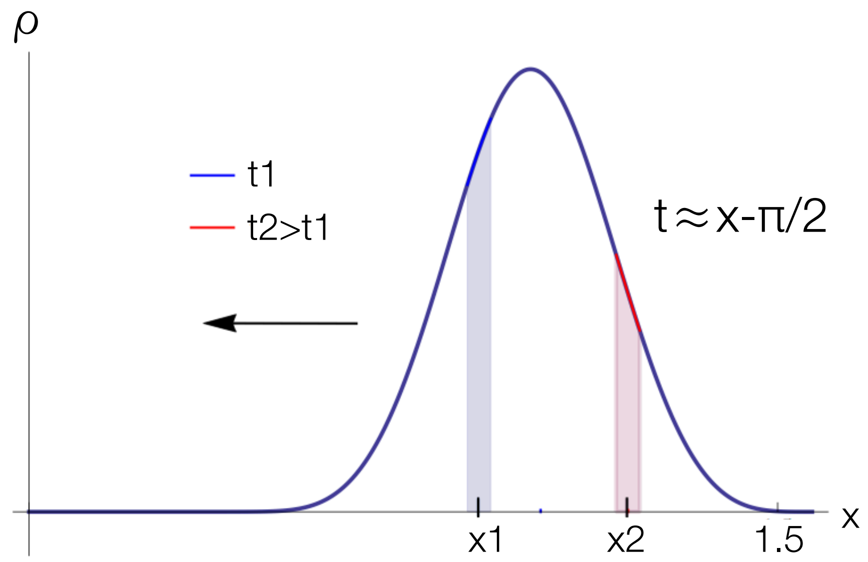
BROAD VERSUS NARROW PULSES

radial position of the pulse ⟷ typical separation of entangled dof

narrow pulses: sudden FT action

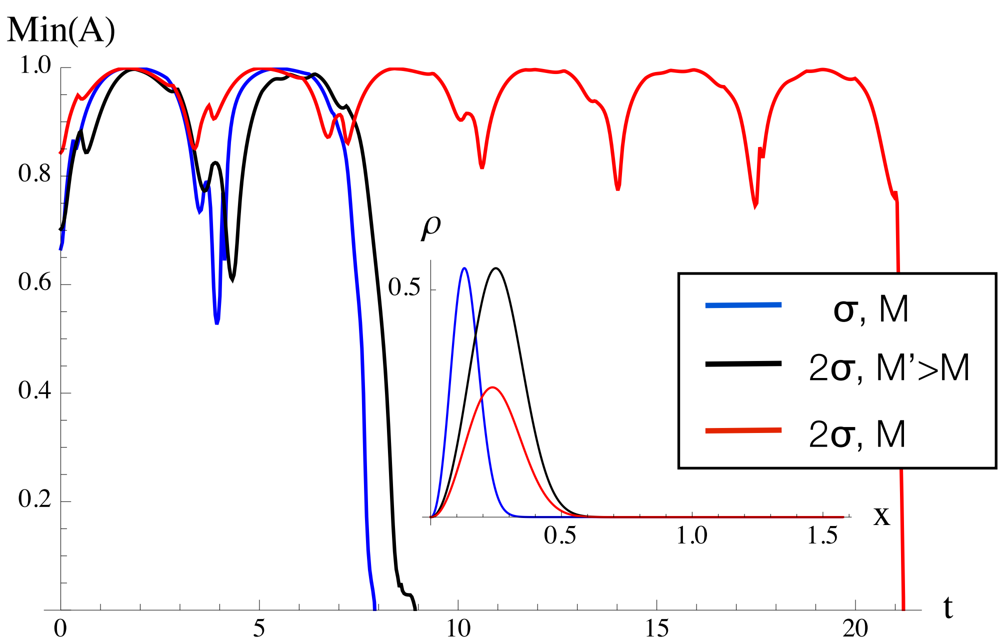
2t < ℓ

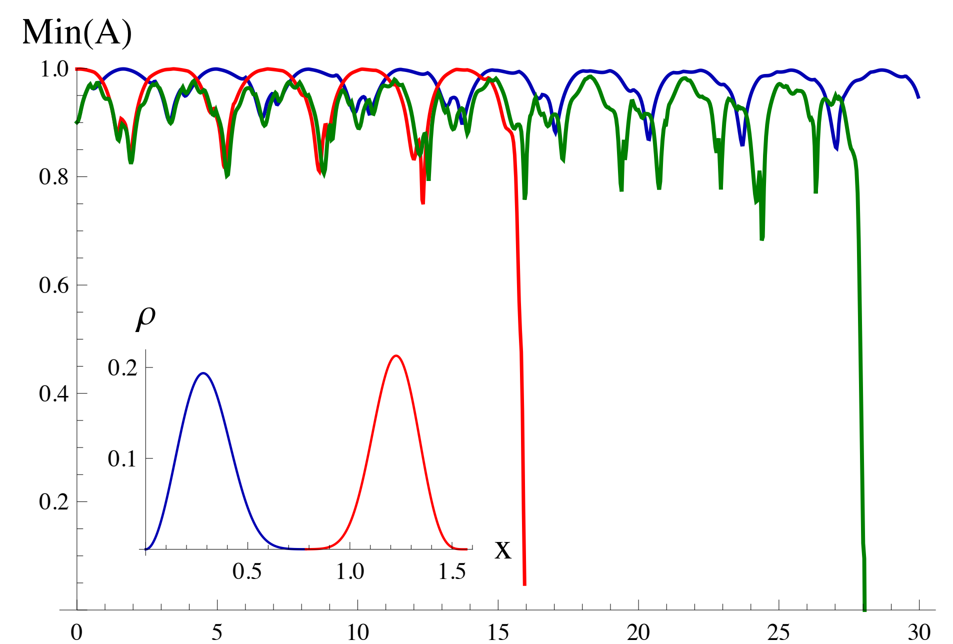




broad pulses: FT actions with a finite time span

BROAD VERSUS NARROW PULSES





time for horizon formation controlled by max(ρ)

scattering of pulses works against weak turbulence

(Buchel,Liebling,Lehener, 2013)

<u>broad pulses:</u>

- no collapse for masses 40% below large BH threshold
- large overlap with the lowest oscillon

REGULAR EVOLUTIONS: DISCUSSION

localized pulses: narrow peak develops (weak turbulence)

relaxation triggered by a subsystem

$\forall$ M

delocalized pulses: entanglement over all scales

partial decoherence unfavored

$M<M_\sigma$, no collapse

CONCLUSIONS

- holography offers a unique setup to study out of equilibrium dynamics

  finite size close systems

- deep relation between Einstein eq. and evolution of entanglement in the dual QFT

  at linearized level (Nozaki,Numasawa,Prudenziati,Takayanagi 2013; Lashkari,McDermott,van Raamsdonk 2013;...)

  MERA approach (Swingle 2009; Nozaki,Ryu,Takayanagi 2012;...)

- dynamics of bounces (weak turbulence) tends to decrease EE

- stepwise relaxation