Thermalization, Chaos, Holography, 1D shock waves

Gautam Mandal

DTP interaction meeting,

TIFR, 8 February 2018

collaborators:
I. (Thermalization): P. Banerjee, A. Gaikwad, A. Kaushal, T. Morita
II. (SYK model): A. Gaikwad, L. Joshi, P. Nayak, S. Wadia
III. (1D shock waves): M. Kulkarni, T. Morita

Thermalization

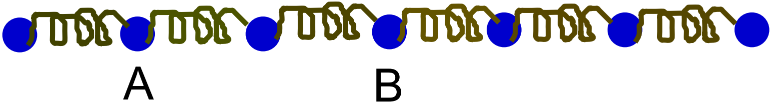
Under what conditions does an isolated non-equilibrium system, described by a time-reversal-symmetric Hamiltonian, approach equilibrium at long times?

Non-equilibrium $\xrightarrow{\text{T}-\text{symmetric Hamiltonian}}$ Equibrium?

If yes, what is the nature of the equilibrium?
What is the rate of approach to equilibrium?

Thermalization in free field theories

This question makes sense even in free field theories (and other integrable models):



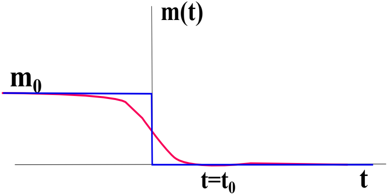
Caldeira-Leggett-Rubin model

Spin model: Transverse field Ising model *Calabrese 2012*.
Cold atom experiments *Kinoshita 2006*.

Steady state is not thermal, but a generalized Gibbs ensemble (GGE).

Quantum quench

Consider a d+1 dimensional free scalar field



d= odd: $\langle O(0,t)O(r,t)\rangle = \langle O(0)O(r)\rangle_{GGE} + \exp[-\gamma t]$

d= even: $\langle O(0,t)O(r,t)\rangle = \langle O(0)O(r)\rangle_{GGE} + t^{-\alpha}$

Note the odd-even difference.

d=odd: exponential relaxation. d=even: power law relaxation.

Banerjee-Gaikwad-Kaushal-GM 2018

Thermal relaxation

$\langle O(0,0)O(r,t)\rangle_{GGE}$ shows the same long time behaviour and odd-even difference. *Banerjee-Gaikwad-Kaushal-GM 2018*

Black hole

For $d = 1$, the exponent γ matches quasinormal decay rates of scalar fields in a black hole background. *GM-Sinha-Sorokhaibam 2015, GM-Paranjape-Sorokhaibam 2015-17*

These black holes have zero Liapunov exponent— integrable theories.

> For even d, power law decay does not match the quasinormal decay of black hole physics.

Ongoing calculation: permutation orbifolds.

SYK model: 'the simplest model of holography'

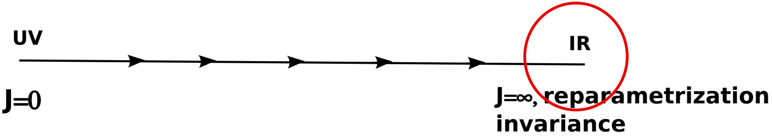
1D stat mech model with Majorana fermions and disorder

Sachdev-Ye, Kitaev 2015

$$\sum_{\tau}\left(\sum_{i}\psi_i(\tau)\psi_i(\tau+a)+\sum_{i<j<k<l}J_{ijkl}\,\psi_i(\tau)\psi_j(\tau)\psi_k(\tau)\psi_l(\tau)\right)$$

$$\langle J_{ijkl}J_{ijkl}\rangle \sim J^2/N^3$$

Solvable at large N.



At low temperature, dominated by (pseudo) Goldstones of broken reparameterization symmetry.

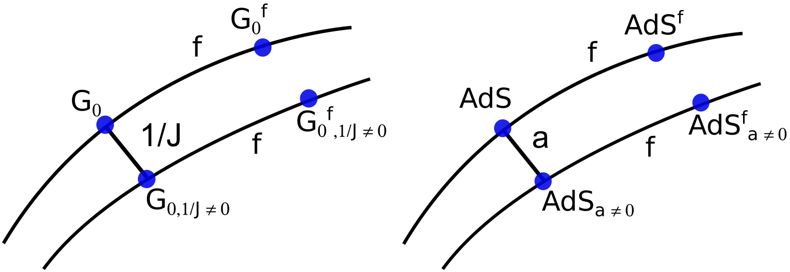
Maximal chaos: $\lambda=\frac{2\pi}{\beta}$, 'Regge' trajectory.

SYK model: holography

Soft sector of 1D SYK $\leftrightarrow$ Polyakov gravity model in AdS_2

Nayak-GM-Wadia 2017.

Pseudo Goldstones are represented by large diffeomorphisms of gravity, which reproduce the 'Schwarzian' effective action of the former.



SYK dual from 3D Kaluza Klein

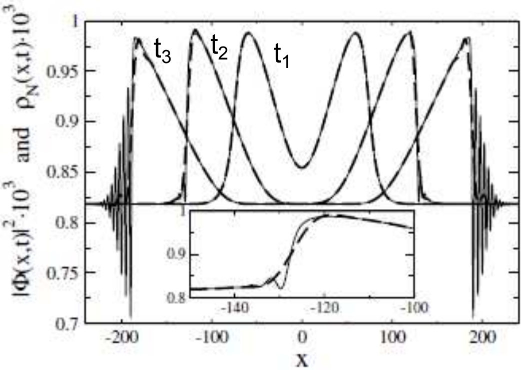
A new approach to the holographic dual: Kaluza-Klein reduction from 3D Einstein-Maxwell reproduces the effective action of the effective action of (pseudo) Goldstones of broken reparamaterization and U(1) gauge transformation.

Gaikwad-Joshi-GM-Wadia 2018 (in progress).

[More in Adwait/Lata's talk]

Shock waves: problem

1+1D hydrodynamics: develops singularities when a shock front forms.



Dashed line= N-body simulation. Solid line= solution of hydrodynamics with `quantum pressure' term. (Damsky et al 2004, 2006; 2015)

Shock waves: resolution

Phase space formulation, developed for c=1 matrix model of string theory resolves the problem. *Kulkarni-GM-Morita 2018*

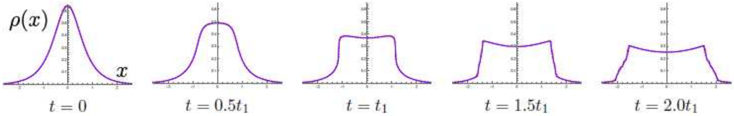


Figure 11: Comparison of real space density using the Euler method (dashed blue line) and the exact quantum mechanical calculation with $N = 50$ (red line). Even after the shock wave formation at $t = t_1$, the Euler method continues to agree with the exact result.