SFT-2019
Lectures on Statistical Field Theories
Galileo Galilei Institute
Florence, 4-15 February 2019

Program of lectures

Bruno Bertini
Transport in closed integrable quantum many-body systems out of equilibrium (6h)

In these lectures I will discuss transport properties of closed quantum many-systems out of equilibrium, focussing on a particular idealised setting where to obtain exact results. Specifically, I will consider the so called "bipartite quench" protocol: the two halves of a system are initially prepared in different thermal states, then they are suddenly joined together and left to evolve unitarily. The goal is to find the stationary currents of conserved charges through the system when first the thermodynamic limit and then the limit of infinite times after the sudden junction are taken.
Outline of the course:
1) I will show that one should expect qualitatively different results in the cases of integrable and generic systems. In particular, only in the former case non-trivial stationary currents are expected to emerge.
2) I will analyse a bipartite quench in a free fermionic chain. I will explain how to find exactly the infinite time limit of all expectation values of local observables (including the currents of conserved charges) by deriving a contour-integral representation of the fermionic correlation matrix and expanding it for large times. This calculation applies also to the case when the position j of the local operator scales with time, i.e. the operator moves on the "ray" j/t.
3) I will revisit the results of the calculation at point 2), presenting a general method (commonly referred to as "Generalised Hydrodynamics Theory") that allows one to find the infinite time limit of every local observable without solving the dynamics. This only required data are the local conservation laws of of the system and the initial state. The working assumption behind the applicability of this method is that expectation values of local observables relax on every ray. This theory admits a very simple interpretation in terms of free classical particles moving from one side of the system to the other with the group velocities of the elementary excitations.
4) I will generalise this approach to the interacting integrable case. I will show that the classical-particle interpretation still applies, but in this case the particles move with "dressed" velocities that encode the effects the interactions.

Prerequisites: Basic Complex Analysis (Contour Integrals, Residues Theorem); Many-Particle Quantum Theory (Free Many-Particle Systems, Second Quantisation Formalism, Wick's Theorem).

Suggested Readings:

- Bipartite quenches:
  - D. Bernard and B. Doyon, J. Stat. Mech. (2016) 064005.
  - R. Vasseur and J. E. Moore, J. Stat. Mech. (2016) 064010.
- Generalised Hydrodynamics:
  - O. A. Castro-Alvaredo, B. Doyon, and T. Yoshimura, Phys. Rev. X 6, 41065 (2016).
  - B. Bertini, M. Collura, J. De Nardis, M. Fagotti, Phys. Rev. Lett. 117, 207201 (2016).

- Homogeneous quantum quenches:
  - F. H. L. Essler and M. Fagotti, J. Stat. Mech. (2016) 064002.

Jérôme Dubail
Classical and quantum hydrodynamics of trapped 1d quantum gases (8h)

I will give an introduction to large-scale descriptions of the dynamics and correlations of one-dimensional gases in inhomogeneous situations (e.g. at equilibrium in traps, or released from traps). I am planning to organize the lectures as follows.

- 0. <u>Technical preliminary: introduction to the 2d free boson CFT:</u> definition in the plane, recipe to calculate correlation functions, conformal mappings, bosonization/fermionization, Dirichlet/Neumann boundary conditions
- 1. <u>Classical hydrodynamics at the Euler scale:</u> continuity equations, separation of scales and the equation of state, discussion of Galilean invariance and Euler equations, hydrodynamics of the Lieb-Liniger gas at zero temperature, application to trap expansions of cold atomic gases. If time allows: a few words about generalized hydrodynamics, or beyond Euler corrections.
- 2. <u>Quantum hydrodynamics of the trapped Tonks-Girardeau gas:</u> Jordan-Wigner transformation and Wigner function of the gas, reduction to tandard hydrodynamics, quantization, application to correlation functions, in particular to the momentum distribution of the bosons.
- 3. <u>The trapped Lieb-Liniger gas at finite repulsion strength:</u> quantization of classical hydrodynamics, inhomogeneous gaussian free field, non-universal prefactors in correlation functions, application to the calculation of correlation functions. If time allows: connection with inhomogeneous problems in 2d classical statistical mechanics (arctic circle).

Prerequisites: some basic intuition of such concepts as relaxation or local equilibrium in systems of many particles. On the more technical side: some familiarity with (free) quantum/statistical field theory, lagrangian formalism, path integrals, Wick's theorem, etc.

Therry Giamarchi
Tomonaga-Luttinger liquids: from field theory to experimental realisations (10h)

Overview:
I) Basic notions of what is a one-dimensional system:
- Introduction to bosonization
- A Zest of numerical approach
- Field theory description of 1D system: the Tomonaga-Luttinger Liquid (TLL)
- Experimental realizations in condensed matter and cold atomic gases

II) Beyond the TLL description:
- Effect of a periodic potential
- Notions of topology and Berezinskii-Kosterlitz Thouless transition
- Experimental realizations
- Double sine-Gordon model and topological phase transition
- Realizations with spin systems

III) Disordered one dimensional systems:
- Basic concepts of Anderson localization
- Notions of Bose and Fermi glasses

IV) Coupled one dimensional systems:

- Case of ladders (spins, bosons and fermions)
- Effect of gauge fields
- Experimental realizations

V) Open issues.

Prerequisites: Good knowledge of “standard many body techniques”, e.g. first three chapters of G. D. Mahan ``Many particle physics" (Springer).

References:

- T. Giamarchi, Quantum physics in one dimension, Oxford (2004);
- M. Cazalilla et al., Rev. Mod. Phys.83 1405 (2011);
- T. Giamarchi, Compte Rendus Physique, 17 322 (2016) .

Giuseppe Santoro

Introduction to Floquet physics (6h)

Floquet physics has to do with periodically driven linear systems. I will start the presentation from the familiar example of resonances in a periodically driven linear pendulum (the swing), moving then to the closely related “dynamical stabilization” of the inverted pendulum (the so-called “Kapitza pendulum”). I will then present the Floquet theorem in the context of a periodically driven quantum Hamiltonian. As simple applications, I will discuss the problem of a periodically driven two-level system, in several variants, including an exactly solvable case. This will lead us to discussing the ``Shirley-Floquet" picture, based on a Fourier expansion, which can be also seen as a tool to effectively increase the dimensionality of the problem.

Frank Verstraete

Introduction to quantum tensor networks: from quantum spin systems to topological quantum order and conformal field theory (8h)

The lectures will give a self-contained introduction to the nascent field of quantum tensor networks. Tensor networks provide a novel way of representing quantum many body states by expressing their entanglement structure in terms of local entangled pairs. This is especially useful for strongly interacting theories for which real space forms the natural basis, and has proven to be an essential ingredient in understanding systems with topological quantum order. The main applications of tensor networks that we will focus on are:

1. the variational simulation of ground states of interacting theories, including quantum field theories;
2. the description of the entanglement structure of topological and critical quantum spin systems;
3. connection between tensor networks, tensor fusion categories, topological quantum field theory and conformal field theory.

Other events

Monday 4 February 2019, 2.30 pm
Gong Seminar‡

Monday 4 February 2019, 5.30 pm
Welcome drink

Wednesday 6 February 2019, 2.30 pm
Seminar:
"Stochastic Effects in Quantum Mechanics"
Denis Bernard (ENS, Paris)

Monday 11 February 2019, 5.30 pm
Wine & Cheese

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‡ Each student is invited to give a two-minute talk to present himself and his scientific interests.