Nonperturbative renormalization theory for interacting many-body systems
Popular summary

Statistical physics considers the general problem of connecting the physical system given at the microscopic scale with its macroscopic properties. At microscopic scales we consider the distinct, individual particles and "fundamental" interactions; while, when observed at a macroscopic scale, the system constitutes a "uniform entity". For example: a piece of metal is composed of a huge number of ions forming a crystal lattice and of free electrons (microscopic particles); while at the macroscopic scale we just see a "piece of metal" (for example a door key). From a practical point of view the information encoded in the microscopic state of the system (for example the positions and velocities of all the individual particles) is completely useless. However, the fundamental and highly relevant question concerns the macroscopic state we obtain when bringing together a large number of particles (of given microscopic properties) at given ambience (for example pressure and temperature). Shall we obtain a gas, a liquid or a crystal, a conductor, an insulator, or a superconductor, a ferromagnet or actually what? And how will the properties of this "something" change when we vary, for example, temperature? Such questions were, clearly, asked already long ago. With celebrated exceptions, the answers provided by theoretical physics can only be given relying on approximate methods, which sometimes fail.

Since 1970s a point of view on this kind of problems was developed known as "renormalization theory". It emphasises the role of the scale Λ on which the system is observed and which may be continuously varied between the values corresponding to the microscopic and macroscopic descriptions. One may consider a whole family of equivalent (i.e. corresponding to the same physical system) descriptions, each of which is assigned to a distinct value of Λ. By varying Λ continuously one may interpolate between the microscopic level (which is a given initial condition in our problem) and the macroscopic observation scale (which we want to describe). This way of thinking led to a solution of a long-standing problem of condensed matter physics (the so-called problem of critical phenomena) and revealed amazing and far-reaching connections between statistical physics and the theory of elementary particles.

In this project we are planning to develop methods based on the philosophy sketched above and apply it to two specific kinds of systems, whose satisfactory theoretical understanding has not been reached until today. These include Bose-Einstein condensates with strong interactions, and unconventional superconductors known as the FFLO (Fulde-Ferell-Larkin-Ovchinnikov) states. Both of these families of system are at the centre of interest of experimentalist as well as theories, which is triggered by groundbreaking advancements in experimental techniques as well as methods of computer simulations. The theoretical description of these is, however, far from complete and not easy to achieve, constituting therefore a demanding challenge calling for new approaches.