Many-body localization - cold atoms approach

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This project is a direct continuation of just finished Opus 10 project under the same title. We have obtained there several interesting results (publication list may be found at http://chaos.if.uj.edu.pl/~kuba/Opus10/), the research planned is a consequence of these results. Thus a popular description is to a large extend similar.

The scientific aim of this project is the analysis of many-body localization in nontrivial models based on cold atomic systems placed in optical lattice potential. Such a potential results from a nonresonant interaction of laser light with atoms. Using counterpropagating laser beams one creates light standing wave resulting in a periodic potential in which atoms move. This resembles the situation of electrons in crystals, except that atoms are electrically neutral. Electron transport in metals is very effective - metals are good conductors. Still in the pioneering work in the late fifties Anderson have shown that randomly placed defects, modelled by addition of the disorder to the system may profoundly affect the transport properties when particles interact with external random potential (but not among themselves). This localization phenomenon is particularly effective in systems with reduced dimentionality (such as one-dimensional chains). This discovery had a profound impact in solid-state physics and was rewarded with Noble prize.

For interacting particles the situation is more difficult and we do not know the full answer yet. This is based on inherent difficulty of the problem which is quite hard to be described by some simplified theories while full numerical analysis is prohibitive. Only in the last 15 years a significant progress has been made resulting in several theoretical papers as well as numerical simulations showing that in the presence of strong interactions and strong disorder the so called many-body localization may appear. Hundreds of papers per year appear on the subject - that shows an immense interest in this topic.

Why this is interesting? The behaviour od interacting particles in an isolated system is of fundamental importance. On one side, knowing initial conditions and following linear quantum mechanics we may theoretically predict the system behavior, on the other, practically this is almost impossible. We expect that due to interactions all local infomation will spead over the whole system. Many body localization limits the transfer of information, so it may be locally contained and then stored to our profit. Many-body localization may lead to the fact that a small subsystem remembers, at least partially, its initial conditions despite interaction with the remaining parts of a given system. thus there is no thermalization due to the contact with the surroundings. The information is not only encoded in the global observables of the full system but also it is stored in local averages or correlations for a subsystem. There is just a single step more (may be not a small step) to quantum storage of information in a similar way as it is presently classically stored on hard discs (using other quantum phenomena).

In the project we plan to perform a detailed analysis of the time dynamics of many body systems in particular similar to that studied in recent experiments with cold atoms. We have at our disposal sophisticated top of the art numerical tools - that will allow us to study realistic system sizes instead of model small systems. It turns out that the latter are strongly affected by finite size effects.