Novel complex many-body strongly interacting systems with an ultracold atom gas featuring large energy scales.

The goal of the project is to construct and study a system in which a gas, cooled down to the temperature just above the absolute zero, shows qualitatively new, rich physics due to inter-atom interactions. Although one could think that ultralow temprature would just freeze the movement of atoms, the reality is different. This wrong prediction would come for misrepresentation of atoms as solid, colliding balls. In ultracold regime, internal structure of atoms manifests itself. It features a number of energy levels with well-defined energies. Light can be absorbed only if its frequency matches the difference between the two energy levels. If the frequency is only close to the difference, then strong atom-light interaction takes place. It allows to create e.g. a regular lattice structure for the atoms, just with laser beam. The distance between the neighbouring vertices in that structure is just 400 nanometers (1 nanometer is one millionth of a millimeter).

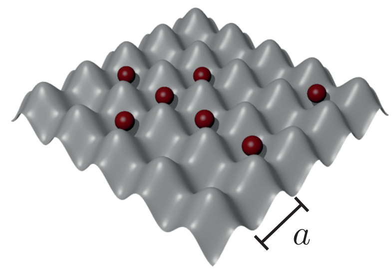

Figure 1: Atoms in optical lattice potential (concept art).

Gas in the lattice can be additionally manipulated, which make the neutral (no electric charge) atoms not only hop between vertices of the lattice, but also to do it in such a way as if they were charged and in presence of magnetic field (Lorenz force simulation). Moreover, such lattice systems can be used to mimic behaviour of more complicated systems. Although, mathematical solution of the simple model may not be possible (without resorting to far-going trivialisation), some of the questions regarding the more complicated model, can be answered by experimental probing of the ultracold lattice implementation. Ultracold quantum gases, allow, for defect-free implementation, controllable with optical means. Moreover, physics of the lattice gas may be altered by laser light — e.g. one can tune interaction between atoms from interactive to repulsive. .

Proposed research is devoted to constructing novel ways of manipulating atoms in the optical lattices, to make them less susceptible to unwanted environmental noise — by finding a new ways to feature the topological protection. This means that interparticle interaction is tuned to structure many-body gas such that it is resilient against little perturbations. To give an intuitive picture, a ribbon winded three times around a hook, remains to be three-fold winded, even if it is pulled or deformed. Counterpart of the physical properties is then the winding number, not the exact shape of the ribbon. To break the order, one would need to drastically alter the ribbon (tear it apart).

Behaviour of the quantum gas can be steered by periodic stimulation (e.g. shaking). A proper choice of frequency and means of stimulation, enables to implement artificial magnetic field for gas of atoms with no electric charge. This project is concerned with extending the above approach to interacting systems. The goal is to model emergence of so-called fractional Quantum Hall effect, which inherently features object topologically protected agains effect of the environment. Project deals with unwanted heating of the system as a subtle interplay of shaking an interaction and study what is the role of the topological structure in suppressing this unwanted process. Early experimental work suggest that substantial shaking is present in such a construction, which should be understood and, if possible, minimized.

Other topologically-protected systems will be constructed by preparing a laser system, to make the atoms change its electronic configuration as it moves — every few hundreds of nanometers. This binds position of atoms with its electronic structure and conditions hopping between lattice sites on presence of the other atom in nearest neigbourhood. This allows to construct complex, novel dynamics of gas in the quantum wires.