Investigation of quantum turbulence in strongly correlated Fermi systems

Liquid flows are phenomena that accompany us every day. They may be either laminar or turbulent. At low temperatures, the occurrence of superfluidity (or superconductivity) is a general feature of most physical systems. It was asked whether there are also laminar and turbulent flow analogs in case of superfluids - liquids that have zero viscosity? Nowadays we know that answer to that question is yes! Superfluid systems can support rotational motion only in the form of quantum vortices. These are objects for which the circulation can take only discrete values, which are a multiple of $\frac{h}{m}$, where h is Planck's constant and m is the mass of the particles constituting the fluid. Because of this, the quantum vortex cannot slow down its circulation and eventually stop spinning (as in the case of vortices in ordinary liquids), but it must spin continuously. Typically, quantum vortices are arranged in regular lattices. This situation is equivalent to laminar flow, see Fig. 1, which depicts a snapshot of the vortex lattice produced in Bose-Einstein condensate. Under certain conditions, the quantum vortices may become "tangled," which visually appears as a spaghetti-like structure. The system exhibits then chaotic dynamics and now we are dealing with analog of the turbulent flow. "Untangling" of the quantum vortices and re-establishing the regular lattices corresponds to a phenomenon of decay of the turbulent state.

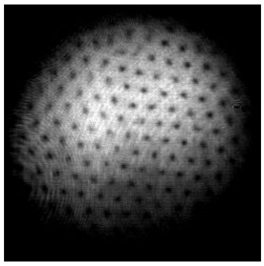

Figure 1: Source: Wolfgang Ketterle - Nobel Lecture: *When Atoms Behave as Waves: Bose-Einstein Condensation and the Atom Laser*.

Famous physicists, like S. Weinberg and R. Feynman, have recognized the phenomenon of the turbulence as one of the biggest unresolved problems of modern science. Indeed, the problem is very complex, and the equations describing this phenomenon are very difficult to solve. However, since Feynman's attempts to face this problem, the situation has changed radically. Today we are equipped with new research tools. On the one hand, these are experimental techniques that allow the cool down atomic gases to almost absolute zero temperature and observe the occurrence of the superfluidity. On the other hand, these are supercomputers, which we can use for solving very complex mathematical equations.

Within this project, we will use the world's largest computer systems and perform numerical simulations that will enable us to shed a new light on the phenomenon of the quantum turbulence. For the first time we will use fully microscopic approach, based on the density functional theory, to investigate the the quantum turbulence state in the ultra-cold atomic gases of fermionic type. Density functional theory is currently the most accurate method to simulate these type of systems that modern science is equipped with. As usual, accuracy and precision have their price: the method requires enormous computing power that can be delivered only by the world's most powerful supercomputers. For this reason, these researches will be pioneering, both from a scientific and a technical point of view.

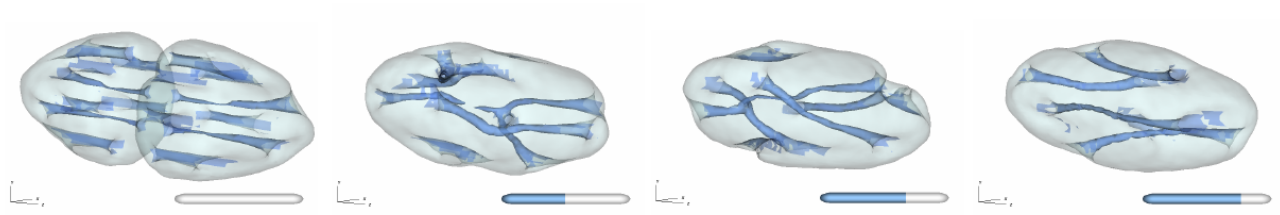

Figure 2: Results of our initial researches showing the formation of tangled quantum vortices as a result of collision of two ultra-cold atomic clouds containing a regular vortex lattice. The pictures show the state of the system in subsequent, selected moments in time. In the last image it is seen that the quantum vortices have untangled and almost re-established the regular lattice again. This initial numerical simulation was performed on the *Titan* supercomputer (USA), currently the world's fourth-largest computing system (as ranked in September 2017). It demonstrates that the present research tools are sufficient to start systematic studies of the quantum turbulence. Figures from publication: A. Bulgac, M.M. Forbes, G. Wlazłowski, *Towards Quantum Turbulence in Cold Atomic Fermionic Superfluids*, J. Phys. B 50, 014001, (2017).