Influence of superfluidity in the time evolution of inhomogeneous structures in a neutron star

The life of a massive star — tenfold heavier than the Sun — will end with a so-called supernova explosion. In the aftermath, a neutron star is born: it has the size of a large city: about 20 km, and a few solar masses. Such squeezed matter has a density similar to the density of the interior of a nucleus. Hence, the matter that builds a star has many exotic properties that are not seen in terrestrial materials. Due to the nature of the neutron star, quantum mechanics is inevitable to describe the matter's properties and phenomena that occur there. Thanks to the sophisticated theories and computer techniques, one can look into the interior of neutron stars, and predict their structure.

A neutron star has a layered structure and under the surface, one can distinguish: outer and inner crust, and the core. In the outer crust, the nuclei form a lattice similar to the one that can be found in metals on the Earth, but thousands of times denser. The pressure resulting from strong gravitation leads to the fact that in deeper layers the protons and electrons create electric neutral neutrons which will constitute the majority of particles. In the inner crust, the high density, small internuclear distances, and abundance of neutrons result in neutrons dripping out from the nuclei to the background. Therefore, the inner crust is formed by a lattice immersed in the background fluid of neutrons which can move without resistance, because they are superfluid.

Just next to the border with the core, there is a thin region in which the nuclei interact strongly with each other and with surrounding neutrons. The interaction leads to destabilization of the lattice but also deforms spherical nuclei. The new shapes are, for example, lines, sheets, even can have a sponge-like structure. A plethora of different phases has been called *nuclear pasta*, because of the diversity of structures and shapes.

The project aims to **study properties of the inner crust**, in particular, to determine the interactions between nuclei and its role in deforming the lattice and creating the nuclear pasta phase. We will use the state-of-the-art modern models that describe interiors of neutron stars and 25 petaflops supercomputers which make $2,5 \cdot 10^{18}$ operations every second. With such help, we will create three-dimensional simulations showing the dynamics of nuclei immersed in neutron matter. From that, we will deduce the interaction between the nuclear clusters.