Motivation

We are interested in superfluid dynamics in various systems, e.g.:

- Vortex-nucleus interaction in the neutron star crust
- Pairing field dynamics in nuclear reactions
- Solitons/vortices in spin-imbalanced fermi gases
- Quantum turbulence in the unitary fermi gas

Method

We employ Time-Dependent Superfluid Local Density Approximation: TDSLDA

To describe superfluid dynamics in strongly-correlated Fermionic systems, we use Time-Dependent Density Functional Theory extended to superfluid systems, TDSLDA [1]. We solve it in 3D uniform grids without symmetry restrictions. Since it requires to solve a large number (10^4 - 10^6) of 3D, non-linear, coupled PDEs, we do need supercomputer. With local treatment of pairing, the equations could be solved efficiently on GPUs: each thread takes care of each lattice point. With the usage of supercomputers, it has been successfully applied to, e.g., collisions of two superfluid nuclei [2] as well as vortex-nucleus dynamics in the neutron star crust [3].

Results

The method was applied to spin-imbalanced superfluid fermionic systems

Cold atoms experiments offer invaluable information on superfluid dynamics, including decay cascades of topological defects. While the cascade properties are well established for Bose systems, our understanding of their behavior in Fermi counterparts is very limited, in particular in spin-imbalanced systems, where superfluid (paired) and normal (unpaired) particles naturally coexist giving rise to complex spatial structure of the atomic cloud.

We have extended TDSLDA to describe spin-imbalanced systems, confirming its ability against experimental observation [1] (top figure). We then showed, that the decay cascades of topological defects are dramatically modified by the spin polarization. We demonstrate that decay cascades end up at different stages: “dark soliton,” “vortex ring,” or “vortex line,” depending on the polarization. We reveal that it is caused by sucking of unpaired particles into the soliton’s internal structure (bottom figures). As a consequence vortex reconnections are hindered and we anticipate that quantum turbulence phenomenon can be significantly affected, indicating new physics induced by polarization effects. Results have been published in Physical Review Letters [2].