

Spin-orbit coupling initially emerged in atomic physics at the beginning of the XX century to explain shifts in energy levels appearing due to interaction between the electron's spin, its orbital motion, and the electrostatic field of the positively charged nucleus. A little while later spin-orbit coupling was successfully generalized to explain a variety of effects resulting from the coupling of the particle's velocity to its quantum mechanical spin. For example, it is essential in solid-state materials in explanation of numerous quantum phenomena where topological insulators and Majorana fermions are great examples.

SOCAT proposes the theoretical study of spin-orbit coupling in atomic vapors at almost zero temperatures when atoms are in the degenerate regime. The main motivation for studying the spin-orbit coupling in ultra-cold quantum gases is the unique experimental control over the system and tunability that facilitates investigation of physics in the parameter regimes unavailable in any other known setting. In particular, spin-orbit coupling for ultracold atoms can be much stronger (in relative units) than that for electrons in solids.

The study proposed in SOCAT concentrates on the utility of the spin-orbit coupling for the dynamical generation of spin-squeezed and entangled states in the system composed of ultra-cold fermionic atoms in an optical lattice potential. The dynamical generation of spin squeezing in ultra-cold atomic gases, which was successfully demonstrated in numerous experiments with Bose-Einstein condensates, is caused by inter-atomic interaction. The usage of the same mechanism with ultra-cold fermions is harder because identical fermions cannot interact via the dominant (s-wave) collisions at ultra-low temperatures. The solution is the implementation of the spin-orbit coupling because it induces an effective interaction among identical ultra-cold fermions. Consequently, it gives rise to the dynamical production of metrologically useful many-body fermionic states. Ultra-cold fermions in optical lattices are used in the most precise and accurate optical lattice clocks. The research to be carried out in the project, and resulting understanding of the squeezing and entanglement production using the spin-orbit coupling, might have metrological applications in increasing the sensitivity of optical clocks.