Spin and charge transport in low-dimensional novel quantum materials

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The aim of this joint proposal is to develop new theories and novel techniques in the field of solid state physics and magnetism concerning topological properties and theoretical modeling of spin and charge transports in novel low-dimensional quantum materials. Recent discovery of two-dimensional systems with giant spin-orbit interaction as well as systems with noncollinear magnetic orders promises a paradigm shift in state-of-the-art spintronic-based technologies in the direction of nanodevices with magnetic and electronic properties design on demand and controllable by external fields.

The new paradigms for electronics are indeed an essential issue since it is expected that in 2025, the global power consumption of IT appliances reaches 4.6 trillion kWh, corresponding to 15% of global power generation. Furthermore, approximately 2.5 quintillion bytes of data are currently created every day. These two staggering numbers clearly show an urgent demand for low-power, ultrafast, and dense processing and storage devices.

We plan to study such novel materials as graphene, van-der Waals heterostructures, topological insulators, or Weyl semimetals. Based on a combination of advanced analytical and computational approaches, we intend to describe systematically nonlinear transport phenomena, non-equilibrium many-body effects (e.g., magnon Bose-Einstein condensates, magnon-plasmon hybridization), and quantum properties of transports (determined by topological properties of band structures) in novel quantum materials.

The collected results indicate the most promising phenomena emerging in new low-dimensional structures functional in a new generation of IT devices.