

**Project Title:**

**Spin Transport in Quantum**

**Name:** Henri Saarikoski

**Laboratory at RIKEN:** Center for Emergent Matter Science /Spin Physics Theory Research Team

**Background :** The research project belongs to the field of condensed matter physics in low-dimensional mesoscopic semiconductor systems. In mesoscopic quantum system interesting spin-related effects as well as topological phenomena are predicted to arise in phase coherent regime. Phase coherence length in semiconductor systems is of the order of micrometers which allows detection of phase coherent phenomena in mesoscopic systems. Interesting physical phenomena in this regime have been predicted and signatures of such phenomena in experimental quantum ring systems needs to be calculated. The project specifically to studies topological transitions of the Lyanda-Geller type (Y. Lyanda-Geller, Physical Review Letters 71, 657 (1993)) in the geometric phases (Berry's phase in the adiabatic limit), and the interplay between the topological transitions and Landau-Zener transitions between the energy bands split by the spin-orbit interaction. Topological transitions of the geometric phase may lead to robust control of phase of electron spin in spin interferometers. The research project has been performed in collaboration with a research group at University of Seville lead by prof. Diego Frustaglia. The role of the Frustaglia group in the project has been calculations of spin transport in the 1D semiclassical ballistic systems. These calculations are important for the determination of phase components in the interference pattern but the method cannot take into account effects of disorder and multiple transport modes. For this purpose large scale numerical 2D calculations were performed at RICC.

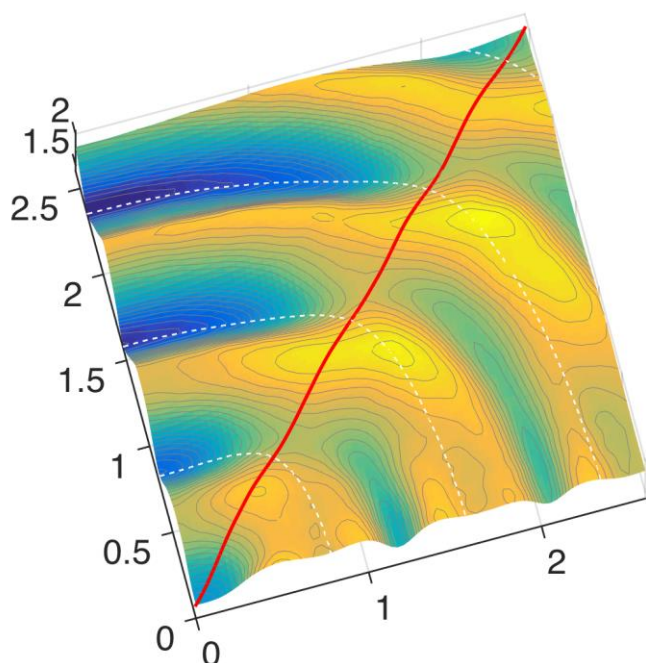
**Calculation method :** General purpose quantum transport codes have been recently released for the scientific community: the Kwant software package is based on the Python programming language

(<http://kwant-project.org/>, C. W. Groth, M. Wimmer, A. R. Akhmerov, X. Waintal, *Kwant: a software package for quantum transport*, New J. Phys. **16**, 063065 (2014)) and direct solution of the transport matrices. Spin transport in semiconductor quantum ring systems is calculated by using the Kwant-code and to some extent earlier recursive Green's function method (RGFM) based package. In the fiscal year 2014 over 264,000 core hours have been used at RICC and results both in ballistic and the in disordered systems have been obtained. The RICC has been used to the maximum level possible. Results of calculations are compared to experiments in samples consisting of quantum ring ensembles performed in Prof. Nitta's group in Tohoku University.

**Results :** The transport calculations indicated that topological transitions in the geometric phase can be obtained using a high in-plane magnetic fields. Geometric phase shift at low magnetic field limit was confirmed in experiments earlier in the Nitta group at Tohoku University (F. Nagasawa, D. Frustaglia, H. Saarikoski, K. Richter, and J. Nitta, Nature Communications 4:2526, September 26 (2013)) and paves way for experiments in high magnetic fields and possible detection of topological transitions in geometric phase. Our subsequent theoretical project with the University of Seville group established that topological transition in electronic spin transport can be controlled via manipulation of spin-guiding fields within experimental reach. The transitions are determined by an *effective* Berry phase related to the topology of the field texture rather than the spin-state structure, irrespective of the actual complexity of the spin dynamics. This manifests as a distinct dislocation of the interference pattern in the quantum conductance of mesoscopic loops. The

phenomenon is robust against disorder, and can be exploited to determine the magnitude of in-situ spin-orbit fields (see Fig. 1 for a multi-mode calculation).

searched for using numerical methods and the RICC cluster. This work is expected to be performed during the fiscal year of 2015.



**Figure 1** Topological transition in a weakly disordered 3-mode quantum ring shows a clear phase dislocation along the critical line where the spin-orbit field and the Zeeman field are equal (red line).

**Conclusions :** The cluster has been used in large scale computations of quantum transport and results indicate that a topological transition in the *effective* geometrical phase is observable in interference pattern in the current through a quantum ring system. The calculations provide very important information about a real signal in experiments and can be used to prepare experiment to confirm this prediction.

**Future Plans :** Simulations of actual experimental situations require heavy calculations at different disorder configurations. The plan is to use large-scale many-parameter simulations of interference experiments to be performed in the Nitta group at Tohoku University. High accuracy diagrams for publications would require 500,000 core hours. In addition alternative experimental setups where topological transitions are important are

**Fiscal Year 2014 List of Publications Resulting from the Use of RICC**

**[Publications and preprints]**

H. Saarikoski, E. Vasquez-Lozano, J. P. Baltanas, F. Nagasawa, J. Nitta, and D. Frustaglia, "Topological transitions in spin interferometers by effective Berry phases" (preprint arXiv:1412.5487, submitted to Phys. Rev. Lett., 2014)

Publications of related a related project of domain wall dynamics in a synthetic antiferromagnet (partly performed using the RICC system)

H. Saarikoski, H. Kohno, C. Marrows, and Gen Tatara, "Current-driven dynamics of coupled domain walls in a synthetic antiferromagnet", Phys. Rev. B 90, 094411 (2014).

**[Oral presentation at an international symposium]**

Presentation at a Joint DFG-JST workshop on Topotronics, Hakone, Japan, March 2014.

**[Others]**

Presentations of the results obtained with the RICC at the following scientific meetings :

APS March Meeting 2014 in Denver, March 2014

Joint Tohoku-Riken workshop in Kaminoyama, Japan. July 2014

4<sup>th</sup> Summer School on Semiconductor/Superconducting Quantum Coherence effects and Quantum Information, Nasu, Japan, September 2014.

Joint Riken-Tohoku workshop, Zao Onsen. Japan, October 2014.

2<sup>nd</sup> CEMS topical research camp, Minakami, Gunma, Japan, October 2014.

Visit at the Department of Physics University of Sevilla, Spain. October 2014.

**External funding :**

Kakenhi Grant, Grant in aid of Scientific Research (C), No. 26390014.