Report of MERIT long-term dispatches abroad

Department of Applied Physics

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Place：University of Tennessee, University of Virginia

Collaborators：Prof. Cristian Daniel Batista, Prof. Gia-Wei Chern

Period：2023/1/10 ～ 2023/2/3、2023/2/11 ～ 2023/3/4

Overview

I visited the University of Tennessee and the University of Virginia in the U.S., and conducted joint research with Prof. Cristian Daniel Batista and Prof. Gia-Wei Chern, respectively. With Prof Batista, we worked on the metastable state of the magnetic structure called the skyrmion lattice, which is a swirling topological spin structure. With Prof Chern, we investigated the dynamics of the skyrmion lattice in metallic magnets by using a computational method based on machine learning.

Report of research

Magnetic skyrmions are swirling topological spin structures and they can not be annihilated by any continuous modifications of spin textures. Owing to their topological properties, magnetic skyrmions bring about intriguing magnetic properties, e.g., spin structure factors and collective excitation modes. In addition, noncolinear and noncoplanar spin textures lead to the emergent electromagnetic field acting on conduction electrons through the Berry phase mechanism, and conduction electrons acquire nontrivial electronic states and quantum transport properties. These swirling spin textures are of great interest in applications to next-generation magnetic devices as well as fundamental physics. Theoretical clarification of the stabilization mechanisms and dynamics of such magnetic structures is particularly important for further development of the research field and future applications.

To broaden my perspective as a researcher through the research on the stability and dynamics of the skyrmions, I visited Prof. Batista and Prof. Chern to conduct joint research with support from MERIT-WINGS. With Prof. Batista, we investigated the skyrmions in nonequilibrium steady states. In chiral metallic magnet MnSi, magnetic skyrmions are stabilized by forming a triangular lattice and it is called the skyrmion lattice (SkL). The SkL is only stabilized in a narrow area in the magnetic phase diagram spanned by temperature and the external magnetic field, whereas the SkL is realized as a nonequilibrium steady state over that area by sweeping temperature. However, systematic studies on the metastability have not been done. In this study, we theoretically investigated the stability of the metastable SkL by using an open-source software package called “Sunny”. First, we clarified interactions between localized spins allowed by crystal symmetry. With these symmetry-allowed interactions, we clarified the metastability of the SkL by numerically solving the Landau-Lifshitz-Gilbert (LLG) equation, which is an equation of motion for localized spins. We clarified that the metastable SkL is realized down to zero temperature by quenching temperature under the magnetic field. Furthermore, we clarified that the lattice structure of the SkL changes from a triangular lattice to a square lattice by decreasing the magnetic field.

With Prof. Chern, we investigated the dynamics of skyrmions in metallic magnets. Several materials hosting the SkL including MnSi are often metallic, whereas the impact of electronic states on the spin textures is still elusive. This problem arises from the difficulty of large-scale simulations for models describing both spins and electrons and hence, the development and the verification of efficient numerical methods are inevitable. In this study, we employed the efficient method to numerically solve the LLG equation with the power of machine learning and investigated the dynamics of skyrmions in metallic magnets. First, we employed the conventional numerical method and executed a small-scale simulation for the model describing a metallic magnet with the Rashba spin-orbit coupling. We clarified that the SkL with a square lattice of skyrmions as well as the stripe spin structure is stabilized by changing the strength of the spin-orbit coupling. Furthermore, we constructed a machine-learning model of metallic magnets based on the feedforward neural network by using the data for the small-scale simulation as training data. We are now employing this machine-learning model to do a large-scale simulation. It is desired to demonstrate an application of machine learning to a large-scale simulation and to clarify the characteristic dynamical phenomena in metallic magnets.

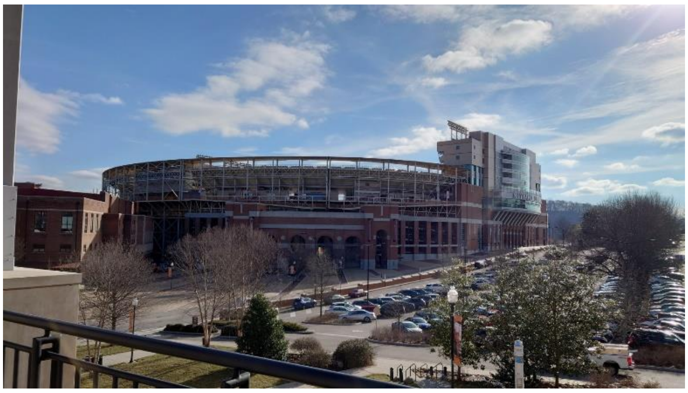

Fig. 1. A huge football stadium in the University of Tennessee.

Life in the U.S.

The University of Tennessee is in Knoxville and this city is the third largest city in the state of Tennessee.

The climate is like that of Tokyo, whereas rainy and cloudy days are somewhat common. The area around the university is safe, and the relatively low cost of living makes it an easy city to live in, even among U.S. cities. The office of Prof. Batista was located near the football stadium of the university. Although the campus was very crowded, the office area was calm and comfortable to conduct the research. The group has three students and two post-doctoral fellows. Each of them is working on an independent topic, and the small size of the lab left a strong impression on me of the abundant communication among the lab members and between Prof. Batista and the members. Through my stay in Prof. Batista's group, I come to intend to engage the daily discussion, share our opinions, and respect each other to proceed with the projects.

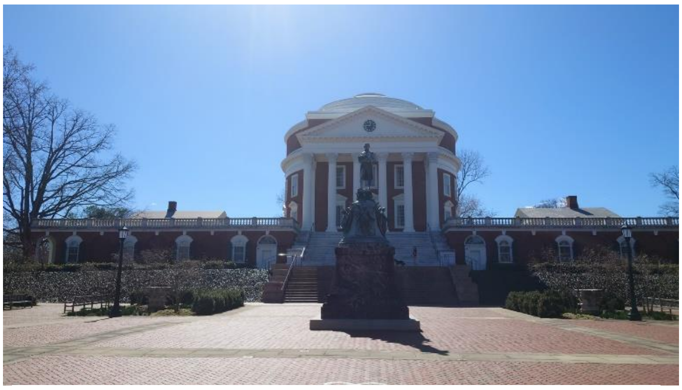

Fig. 2. The Rotunda in the University of Virginia.

The University of Virginia is in Charlottesville in the state of Virginia, and this is a small city located one and a half hours southwest of Washington by train. The climate is similar to that of Tokyo, and the cost of living is less expensive compared to the other part of the United States. The university itself has been selected as a World Heritage Site, and many visitors come to Charlottesville to see the campus. The office of Prof. Chern's group is located about a 15-minute walk from the Rotunda, which is an iconic building of the university. We can discuss almost every day and were able to make good progress in our research. I also frequently discussed with the experimentalists and this opportunity also made my research life very fruitful.

Acknowledgment

I would like to thank Prof. Batista and Prof. Chern from bottom of my heart for accepting my request to conduct joint research. Daily life in the U.S. was supported by the staff and the students in the groups. I would also like to express my gratitude to all of them. I would like to thank Prof. Yukitoshi Motome, Prof. Eiji Saito, and MERIT-WINGS program for their giving me this opportunity. This dispatch was supported by Grant-in-Aid for Scientific Research Grants (No. JP21J20812) and School of Engineering Musha Shugyo 2022 program.