

# Report on MERIT Long-term Overseas Dispatch

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## Overview

From June 5<sup>th</sup> of 2017 until July 31<sup>st</sup> I have stayed at the city of Cologne in Germany and conducted a collaborative research with Professor Simon Trebst group in University of Cologne. The research theme was on the finite-temperature phase transitions between low-temperature quantum spin liquids (QSLs) and high-temperature paramagnets in three-dimensional Kitaev models. Also, I presented my research results as a poster presentation at the International Conference on Strongly Correlated Electron Systems 2017 (SCES 2017) held in Czech Republic in the city of Prague from July 17<sup>th</sup> until July 21<sup>st</sup>. In addition to the acquaintance of my supervisor Professor Motome with Professor Trebst, I had an opportunity of discussing with Professor Trebst by myself at the International Symposium on Topological Phases and Functionality of Correlated Electron Systems 2017 (TPFC 2017) held at ISSP, University of Tokyo, from February 20<sup>th</sup> to February 22<sup>nd</sup>, where I presented my research result as a poster presentation. He was highly interested in my research, and it was the beginning of this collaboration through this long-time overseas dispatch.

## Research in Germany

Recently, Professor Trebst group is carrying out theoretical research on QSLs. The QSL is a new state of magnetic insulators realized when quantum fluctuations are strong enough to suppress magnetic ordering down to the lowest temperature. They are attracting interest not only from the fundamental research but recently also from the application to quantum computation. Among the variety of QSLs, the Kitaev model has recently been studied intensively as it realizes an exact QSL in the ground state. This model has attracted a lot of attention from both experimental and theoretical points of view since it may give a good description of magnetic interactions in some magnetic insulators with strong spin-orbit coupling. Professor Trebst and his group members extended the Kitaev model to a variety of three dimensional (3D) lattices and studied the ground states systematically. Classifying the ground state QSLs on a variety of 3D lattices, they successfully obtained the understanding of universal aspect of Kitaev QSLs, and eventually a new insight into the novel QSLs.

On the other hand, in the laboratory of Professor Motome to which I belong, the finite-temperature properties of the Kitaev models have been studied. During my master course I was studying finite-temperature properties of the 3D Kitaev models. In order to understand the universal aspect of the new type of phase transition between the low-temperature QSL and the high-temperature paramagnet on the hyperhoneycomb lattice found in the previous study, we have studied another 3D lattice called hyperoctagon. To calculate much larger systems we have improved the numerical method and achieved the largest calculations in the world. By applying this method to the hyperoctagon Kitaev model we have found that the model also exhibits a phase transition similar to the hyperhoneycomb case. We have also revealed that the properties of such a phase transition are highly related to the ground state properties of the system.

During this long-term overseas dispatch my main purpose was the fusion of the knowledge on the ground states of various 3D Kitaev models in Professor Trebst group and an experience on the efficient finite-temperature calculations developed by me in order to conduct a collaborative research on the variety of 3D Kitaev models. Particularly, during my stay in Germany, first of all we exchanged the information and skills we have and then we started calculations on 3D lattices not calculated before. By doing TV meetings between the University of Tokyo and University of Cologne we accelerated the collaboration and succeeded in obtaining some preliminary results. For example we found the possibility of absence of a phase transition because of the peculiar geometrical constraints of the lattice, and we are continuing the collaboration on this case after I came back to Tokyo. In addition from October of this year a Ph.D student from Professor Trebst group will come to the Motome laboratory for a long period in order to continue and further accelerate this collaboration.

### [Life in Germany](#)

During this long-term overseas dispatch I stayed in the city of Cologne, which is among the biggest cities in Germany. Cologne is situated in the north-east of the Germany and has a very long history. The oldest and the most famous building in Cologne is the Cologne Cathedral. The construction of the building lasted for 600 years and even now it is one of the biggest Gothic Churches in the world, which is the symbol of Cologne. During my stay although I have been coming to the University of Cologne by train and could see Cologne Cathedral every day, the sight of Cologne Cathedral did not make me boring. The climate in Cologne is moderate and during my two month stay the weather was mostly sunny. In addition there are a lot of parks in the center of the city and it is suitable for a relaxed and steady life so I could concentrate on my research.



### Cologne Cathedral

The University of Cologne which I visited during this long-term overseas dispatch is situated nearly in the center of the city. There is no any “campus” in the University of Cologne and all the buildings of the university are spread all over the city. Also you can find some buildings just inside the enormous park surrounding the center of the city. The transportation in Cologne is rather dense, so you can reach the University of Cologne from all directions and even combine the trip to the university with the trip around Cologne by different trains that indeed I tried. The buildings in the university are new and the university itself has very good facilities. Also students of the University of Cologne were very good in speaking English and there were no any problems in communication.

My accommodation was completely outside the city so during my stay in Germany I could experience not only the city life but also experience urban life. The trip to the

university took about 40 minutes and such a travelling every day made my life in Germany more fulfilled, especially because I could enjoy beautiful sights of German villages from the window of the train. Moreover I could see the Cologne Cathedral every day and learn a lot of German language from the announcement in the trains.

Also I have to tell about studying in Cologne University. In the Trebst laboratory you can discuss with everyone in the group at any time and they always will find some time to answer you. Also the laboratory has very strong connections with other laboratories in the same building or laboratories conducting related research. Such an atmosphere has a good influence on my research. I can also say that in the Motome laboratory and in Department of applied Physics to which I belong we have similar atmosphere so I could do my research efficiently in Profesor Trebst laboratory too.

Finally I can say that stay in Cologne was a great experience and had a good influence on both my oncoming daily life and research life. I believe that my collaborative research will last in future and I am willing to visit Cologne again in near future.

### [Research presentation in Czech Republic](#)

During my stay in Germany I also had an opportunity of visiting the city of Prague in Czech Republic for one week in order to present my research results. There I presented poster based on the research during my master course and also during my stay in Germany. I could spend a fulfilled time discussing my research and also getting insight into recent research achievements related to my study.

## Acknowledgement

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