Report of UHH-KU Joint Research Project

Section 1

Project title:		The quantum nature of magnetic skyrmions – ingredients to future quantum technology?
Project coordinator (KU) **Name** **Position** **Faculty, department**		 Robert Peters Senior lecturer Kyoto University, Graduate School of Science, Department of Physics
Project coordinator (UHH) **Name** **Position** **Faculty, department**		 Thore Posske Head of group MIN, Physics, I. Institute for Theoretical Physics
Period of project		From: July 6, 2022 To: July 5, 2023
Project location		KU: ☑ UHH: ☐ (UKE) Other:
No. of participants	**For events**[*1]	[KU] Faculty members: 1 Students: 1 Others: [UHH] Faculty members: 1 Students: 5 Others: Others: *A participant list can be attached instead of completing the above section. The list should include the details above.
	For other exchange activities (such as researcher visits and online meetings) [*2]	[KU] Faculty members: 1 Students: 1 Others: [UHH] Faculty members: 1 Students: 1 Others: Others:
URL at which project outcomes can be viewed (e.g. workshop notifications/programs/reports, evidence of academic papers published or otherwise made available, etc.)		
Photographs with captions		Please submit digital files (such as JPEG or GIF files) of the photographs used in your report as attachments. The size of each image should be approx. 4MB, so that it can be used for printed materials. Please ensure that none of the photographs submitted will cause any issues relating to portrait rights.

[*1] Please enter the number of participants for each event.
[*2] Please count each individual participant once only, even if they participate multiple times.

Section 2

Summary of the project (approx. 200 words)
*KU project leaders are required to submit a summary of the project in Japanese in addition to the English summary (approx. 400 characters).

The quantum nature of magnetic skyrmions - Ingredients of future quantum technology?

Magnetic Skyrmions are topologically protected magnetic textures and have been experimentally observed in correlated materials, e.g., in MnSi and EuO. In a magnetic skyrmion, the local direction of the spins (magnetic moments) depends on the position, stretching over all possible directions of a sphere. Magnetic skyrmions are anticipated to be used in future memory and logic devices because of their compactness and stability. Furthermore, magnetic skyrmions create an emergent electromagnetic field, which is responsible for exciting phenomena such as the topological Hall effect. Magnetic skyrmions have been intensively studied using classical models; the quantum nature of the constituting particles has been mostly neglected. However, when devices become smaller, and in sight of the recent quantum revolution, the classical approach misses an important part of the skyrmions' nature. Yet, calculations of quantum skyrmions are challenging. One would need a quantum computer to simulate them efficiently. Therefore, our project explored novel approaches how to numerically understand quantum skyrmions. We took two approaches that have not been followed so far: (1) *The quantum skyrmion is formed by localized electrons and their magnetic moments (2) Artificial neural networks and machine learning techniques help analyzing the quantum properties of the complicated and memory-intense skyrmion ground states.*

By combining the excellence in natural sciences of UHH and KU, we were able to shed light on the quantum nature of magnetic skyrmions by these techniques and have found that (1) Quantum skyrmions can create a quantum skyrmion Hall effect, similar to the famous quantum Hall effects of topological electronic systems (2) The central spin of quantum skyrmions is unentangled to the remaining spins. This property is an interesting feature for possible future experiments and applications of magnetic skyrmions to build next-generation quantum technologies.

磁気スキルミオンの量子的側面 - 将来の量子技術の構成要素**?**

磁気スキルミオンは、トポロジーに保護された磁気テクスチャであり、MnSi や EuO などの相関物質で実験的に観察されています。磁気スキルミオンのスピンは位置によって球のすべての方向に指しています。 磁気スキルミオンは、緊密と安定性のため、将来のメモリやロジック デバイスでの使用が期待されています。 さらに、磁気スキルミオンは、トポロジカル ホール効果などの興味深い現象の原因となる電磁場を作り出します。 磁気スキルミオンは、古典的なモデルを使用して研究されてきました。 今まで磁気スキルミオンの量子側面はほとんど無視されていました。 しかし、デバイスがより小さくなり、最近の量子革命を視野に入れると、古典的なアプローチではスキルミオンの性質の重要な部分が見落とされます。 一方で、量子スキルミオンの計算は困難です。 それらを効率的にシミュレートするには、量子コンピューターが必要です。 したがって、私たちのプロジェクトでは、量子スキルミオンを数値的に理解するための新しいアプローチを探りました。 (1) 量子スキルミオンは局在電子とその磁気モーメントによって形成される 。(2) 人工ニューラル ネットワークと機械学習を使用し、量子磁気スキルミオンの量子特性を解説する。 UHH と KU の自然科学の卓越性を組み合わせることで、これらの手法によって磁気スキルミオンの量子的性質に光を当てることができ、**(1)** 量子スキルミオンは有名な量子ホール効果に似た量子スキルミオン ホール効果を生み出すことができることを発見しました。 (2) 量子スキルミオンの中心スピンは残りのスピンと絡み合っていない。 この結果は、量子スキルミオンを使用した次世代の量子技術を構築あるいは将来の実験とその応用にとって興味深い特徴です。