Skyrmion phase on a frustrated breathing kagomé lattice

Max Hirschberger¹, Taro Nakajima¹, Shang Gao¹, Licong Peng¹, Akiko Kikkawa¹, Takashi Kurumaji¹, Markus Kriener¹, Yuichi Yamasaki¹2,3, Hajime Sagayama⁴, Hironori Nakao⁴, Kazuki Ohishi⁵, Kazuhisa Kakurai¹5, Yasujiro Taguchi¹, Xiuzhen Yu¹, Taka-hisa Arima¹6, and Yoshinori Tokura¹6

¹RIKEN Center for Emergent Matter Science, ²National Institute for Materials Science, ³Japan Science and Technology Agency, ⁴High Energy Accelerator Research Organization, ⁵Comprehensive Research Organization for Science and Society, ⁶The University of Tokyo

1 Abstract
Recently, our group has experimentally realize [1-3] theoretical predictions [4,5] of a new class of skyrmion host compounds with centrosymmetric space groups. In contrast to skyrmions stabilized by Dzyaloshinskii-Moriya interactions [6], skyrmions here emerge due to frustrated interactions [4] or due to higher order terms included in the Kondo Hamiltonian describing local moment magnets coupled to a Fermi sea [5]. Gd₃Ru₄Al₁₂ is a good metal with Heisenberg-type Gd³⁺ moments, where competing interactions are realized due to the symmetry of the lattice. We have experimentally observed the skyrmion phase and competing magnetic orders using resonant elastic x-ray scattering (REXS) at the Gd-L₂ edge using beamline BL-3A [2].

2 Main
Centrosymmetric materials with relatively high (hexagonal or tetragonal) symmetry are an emerging focus in the hunt for topological spin textures [1-3]. Here, competing Heisenberg-like interactions or four-spin terms (e.g. in the RKKY-expansion of the Kondo Hamiltonian) can realize complex magnetic orders such as spirals and skyrmion vortices. As compared to skyrmions in centrosymmetric materials (e.g. MnSi [6]) or at interfaces [7], Dzyaloshinskii-Moriya interactions (DMI) are absent or cancel out globally. Characteristically, spin textures in centrosymmetric materials condense at much shorter length scales (~2−3 nanometers) as compared to the typical DMI case (~10 − 300 nm), and generate a very large emergent magnetic field $B_{em}$. The latter is thought to drive large transport and magneto-optical responses [8], as well as new functionality [9].

Gd₃Ru₄Al₁₂ crystallizes in a quasi-layered structure of P6₃/mmc space group, with perfectly planar sheets of Gd³⁺ magnetic ions in a distorted (‘breathing’) Kagome lattice (Fig. 1). The Ru sublattice, forming a triangular net, is largely responsible for electronic conduction. As compared to another compound, Gd₃PdSi₃, the present material is more metallic and boasts a qualitatively different phase diagram, where a transverse conical state competes with the skyrmion lattice at low temperature $T$ (Fig. 2). This indicates that manipulation of magnetic anisotropy is important in the control of topological spin textures in centrosymmetric magnets.

We studied REXS at BL-3A of Photon Factory using large, polished single crystals in reflection geometry inside the 8 Tesla superconducting magnet [2]. With the aid of polarization analysis, scattering from the $q = (0.23, 0, 0)$ reflection was observed in several phases. At the lowest temperature ($T = 2.4$ K), we identified helical order in zero magnetic field ($H = 0$), followed by a transverse conical and a fan-like state as $H$ is increased. At higher temperature ($T \approx 8$ K), within the boundaries of the SkL phase as determined from bulk characterization, transport, and Lorentz-transmission electron microscopy [2], we observed REXS intensity consistent with two volume fractions: a helical-type state (the skyrmion lattice) coexists with fan-like order. As the helical nature of the skyrmion state cannot be tested in LTEM, REXS provided very important input for the interpretation of our combined experimental results.
References

* arima@k.u-tokyo.ac.jp