Stability and dynamics of different 3D spin textures in multilayers

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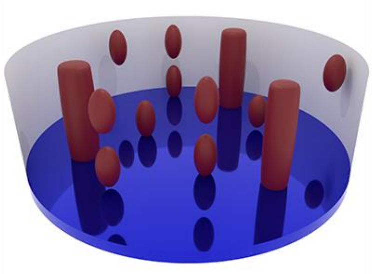
One fascinating phenomenon in physics is the possibility that qualitatively new behaviour can emerge from large ensembles of simple entities, especially in the presence of competing interactions. Magnetism offers a particularly rich playground in this respect because a multitude of competing interactions (e.g., interactions with short and long range, axial, directional, collinear, and chiral character) meets a vector degree of freedom by which complex, topologically non-trivial collective states can be constructed. Magnetic skyrmions are a prime example of such a topological spin texture, which exhibits collective quasi-particle behaviour that is very different from the physics of the individual constituent spins (e.g., gyrotropic deflection, topological damping, etc.). However, while the zoo of 2D emergent topological spin states (vortices, skyrmions, target skyrmions, etc.) is already well explored, the richness expected in 3D is just starting to become accessible.



In this PhD thesis, we propose to investigate experimentally the physics of discretized 3D partial skyrmion tubes or of 3D cocoons [1]—the simplest siblings of skyrmions in magnetic multilayer materials. These states are characterized by a skyrmion structure in some of the magnetic layers and a topologically trivial configuration in others, and as such represent a conceptual novelty compared to any texture in 2D since the topological charge becomes a quasi-continuous number. We refer to these states as “discretized” because of the alternating stacking of magnetic and non-magnetic layers in magnetic multilayer materials, which is important because it permits the existence of such states without energetically costly Bloch points. This PhD proposal is motivated by our recent observation of such 3D states in aperiodically stacked multilayers [1,2], and by our hypothesis that the same states are responsible for the phenomenon of ultrafast laser-induced topological phase transitions by serving as catalysts to overcome the otherwise prohibitively strong topological energy barriers in 2D systems. Our goal is to validate this hypothesis and to uncover the basic physical properties of discretized 3D partial skyrmions on the way. Our approach is characterized by interdisciplinarity between the fields of materials science (exploring the stability phase space), highly advanced coherent x-ray imaging (resolving the 2D and 3D spin textures in collaboration with synchrotron teams), spintronics (confirming the quasi-particle properties of 3D partial skyrmions through their spin-orbit torque driven motion) and ultrafast science (tracking the transient gradient of magnetic properties and the vertical propagation of topological switching after ultrafast laser exposure).

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<u>Applicant skills</u>: Taste for experimental physics; Excellent background in nanomagnetism and spintonics; Programming skills for imaging processing; Basics in micromagnetic simulations.

[1] M. Grelier *et al*, “Three-dimensional skyrmionic cocoons in magnetic multilayers”, *Nature Communications* **13**, 6843 (2022)
[2] M. Grelier *et al*, “X-ray holography of skyrmionic cocoons in aperiodic magnetic multilayers”, *Physical Review B* **107**, L220405 (2023)