CENTRE D'ÉLABORATION DE MATÉRIAUX ET D'ÉTUDES STRUCTURALES

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Formation and stability of magnetic hopfions in chiral magnets

Internship supervisor(s)	name: Dr. Dongzhe Li e-mail: dongzhe.li@cemes.fr group: **M**aterials and devices for **E**lectronics and **M**agnetism (MEM)
Location	CEMES-CNRS 29 Rue Jeanne Marvig, 31055 Toulouse - FRANCE
This research master's degree research project could be followed by a PhD	☒ YES ☐ NO

Topological spin textures play a central role in modern magnetism. Their unique properties have attracted significant attention for both fundamental research and spintronic applications. To date, the main focus of the community so far has been on topological magnetization structures in two-dimension (2D), such as domain walls, vortices, and skyrmions.

Theory predicts that we could form three-dimensional (3D) topological solitons, magnetic hopfions, if the two ends of a skyrmion are connected. Despite extensive research in recent years, direct observations of hopfions in crystals remained for a long time an unsolved problem. A breakthrough occurred in 2023 when scientists created and observed a stable hopfion in a solid [1]. Thanks to their intricate texture and three-dimensionality, hopfions may lead to a new generation of high-density, energy-efficient computing and memory devices, for example, supervised learning with 3D solitons. From a fundamental perspective, hopfions open a novel research avenue called *3D topological magnetism*.

The goal of the internship is to exploit the formation mechanism of hopfions in chiral magnets. This will be done by developing a multiscale approach that combines *ab initio* theory with atomistic spin models. The stability of hopfions will be investigated using the geodesic nudged elastic band method. Finally, we will employ high throughput first-principles calculations to predict novel materials capable of hosting magnetic hopfions.

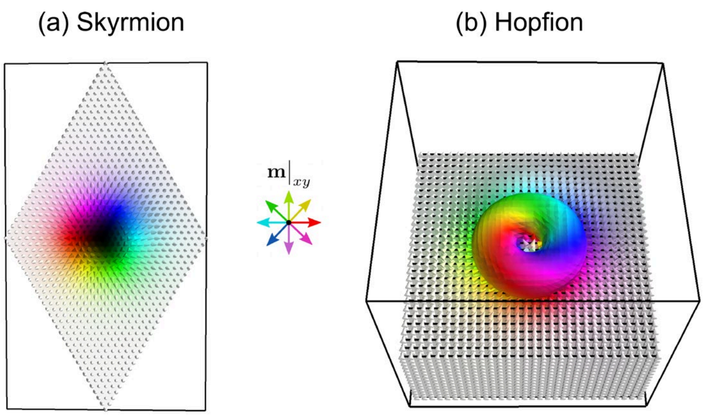

Figure 1: Topological spin textures in 2D and 3D. (a) Skyrmions are 2D vortex-like spin structures that arise in certain magnetic materials. (b) Hopfions are 3D topological solitons with vortex-like closed strings (knots).

This internship requires a taste for modeling. The numerical calculations will be performed using local and national HPC facilities. The results obtained will be analyzed with the possibility of publication in international scientific journals.

References:
[1] F. Zheng *et al.*, Nature **623**, 718 (2023).

Keywords, areas of expertise	Density functional theory, Spintronics, spin-orbit torque, 2D materials
Required skills for the internship	- Master in Physics, Nanosciences, Materials science, or any other equivalent majors. - Good background in quantum mechanics and solid-state physics. - Programming skills (Fortran, Python, or Bash) are not mandatory but will be considered an advantage.

How to apply?
Please send a CV, a copy of the last two years' transcripts (relevés de notes), and a letter of motivation to dongzhe.li@cemes.fr with the following title "M2 internship CNRS".

Starting date and work location
Master internship: 02/2026 – 08/2026
Lab: CEMES-CNRS, Toulouse, France

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