Magnetic Hopfions Induced by Laser

Xiaowen Chen,[1] Nikolai S. Kiselev,[2] Filipp N. Rybakov,[3] Donghai Yang,[1] and Fengshan Zheng[1]

[1]*South China University of Technology, Guangzhou, China*
[2]*Forschungszentrum Jülich, Germany*
[3]*Uppsala University, Sweden*

Magnetic hopfions are three-dimensional topological solitons. To a first approximation, they can be viewed as spin textures formed by closed loops of skyrmion strings. To date, magnetic hopfions have been observed only in special configurations, where they are bound to skyrmion strings [1]. Although theory predicts the existence of stable, isolated hopfions in frustrated magnets [2] and chiral magnets [3], their experimental realization has remained elusive. Here, we report the laser-induced nucleation and direct observation of isolated magnetic hopfions in a B20-type FeGe crystal using transmission electron microscopy (TEM) [4]. We systematically map the nucleation conditions as a function of laser fluence and external magnetic field. A quantitative comparison between experimental measurements and micromagnetic simulations shows excellent agreement, providing unambiguous evidence for the formation of isolated hopfions and revealing their three-dimensional magnetic structure. We derive the appropriate topological invariant for hopfions embedded in helical and conical magnetic backgrounds and show that the relevant homotopy group is $\pi_3(\mathbb{S}^2, \mathbb{S}^2 \setminus \{P_1, P_2\}) = \mathbb{Z}$. We present a practical procedure for computing the Hopf index and apply it to the experimentally observed textures. Finally, we demonstrate that these hopfions are stable without geometrical confinement and can coexist and interact with other topological spin textures.

References:

[1] F. Zheng, et al., Nature 623, 718 (2023).
[2] F. N. Rybakov et al., APL Mater. 10, 111113 (2022).
[3] J.-S. B. Tai & I. I. Smalyukh, Phys. Rev. Lett. 121, 187201 (2018).
[4] X. Chen, et al., preprint on Research Square https://doi.org/10.21203/rs.3.rs-7435743/v