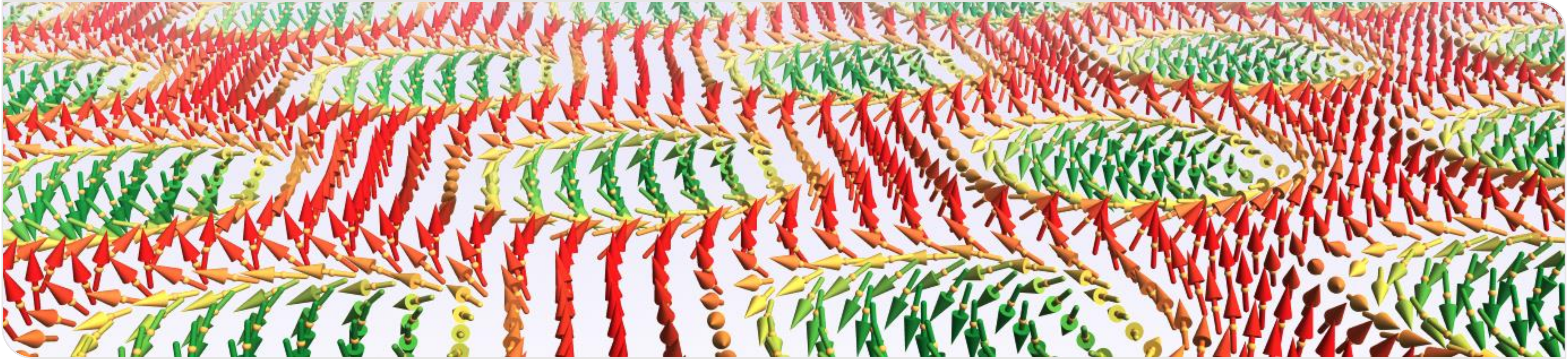
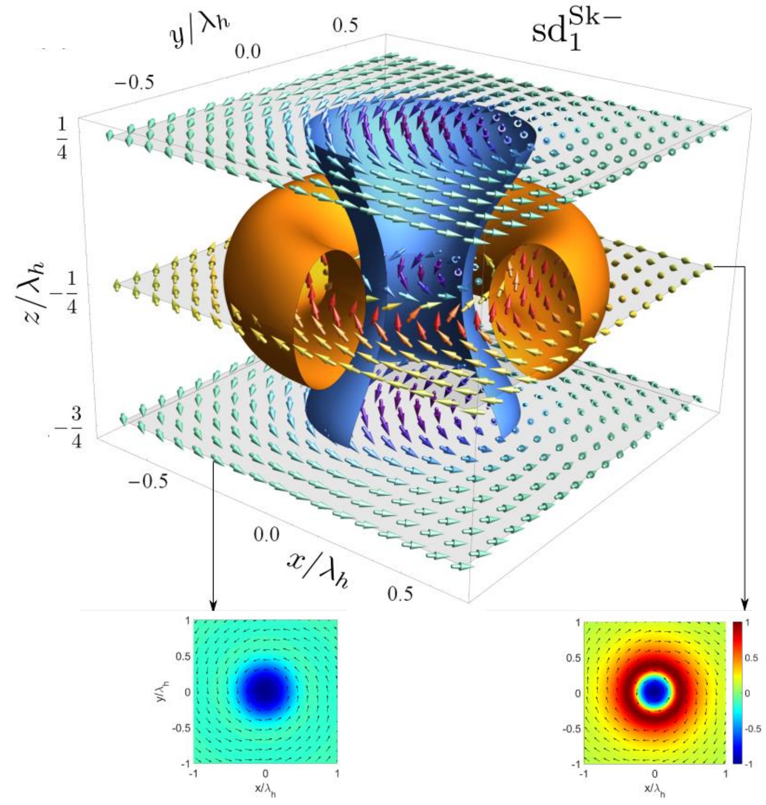
Karlsruhe Institute of Technology

Master Projects in the Institute for Theoretical Solid State Physics

Group Prof. M. Garst



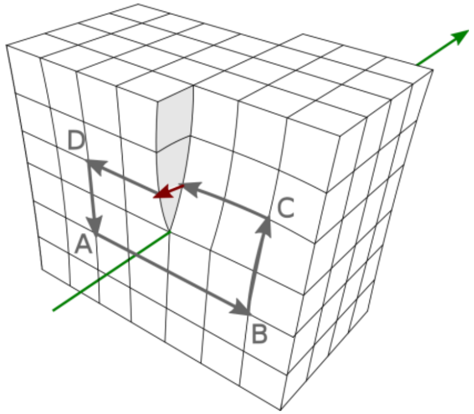
Phys. Rev. Lett. **128**, 157204 (2022)



Simulations of screw dislocations in chiral magnets

In special types of magnetic solid materials known as "chiral magnets", the magnetisation can be treated as a continuously varying vector field. This magnetisation texture can form a simple configuration where all the vectors are parallel, or it can form a helical spiral, where the magnetisation rotates around an axis, as a function of one spatial coordinate. In chiral magnets, topologically protected defects such as the skyrmion or the hopfion can exist. Due to their topological protection, these defects are relevant for application in magnetic storage materials. We will investigate the static and dynamic properties of a new type of (a newly discovered) topological defect known as a "screw dislocation".

The project involves numerical simulations, using the MuMax software, to investigate the effects of external magnetic field and charge or spin current, to investigate the interactions between screw dislocation lines, and their interactions with other types of topological defects. The results of the simulations will be described analytically, for example by studying the equations of motion for this problem. A comparison with experimental observations is also envisaged in future collaborations with experimental groups.



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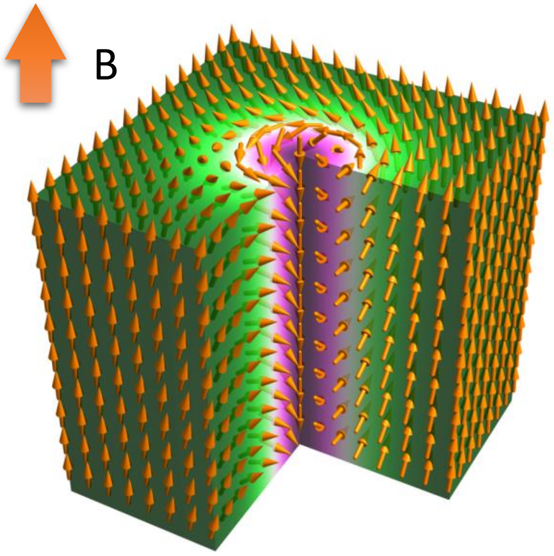
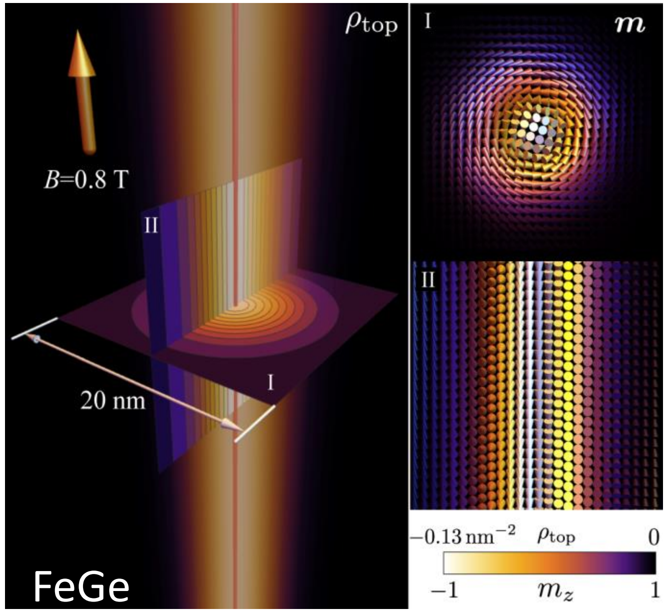
Nonlinear dynamics of skyrmion strings.

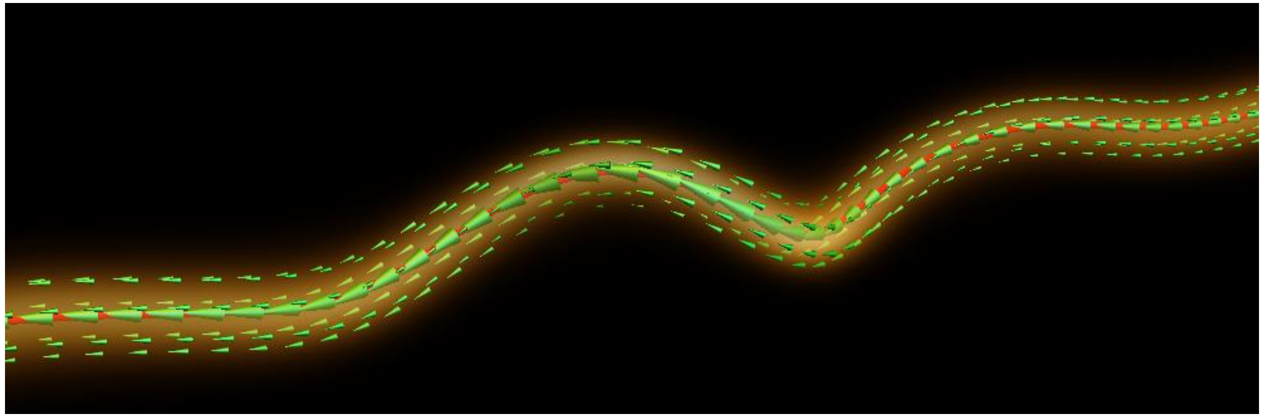
Concept of skyrmion string



$$\rho_{\text{top}}(\boldsymbol{r}) = \frac{1}{4\pi}\boldsymbol{m}(\partial_x \boldsymbol{m} \times \partial_y \boldsymbol{m}) \qquad \mathcal{N}_{\text{top}} = \int \rho_{\text{top}}\, dxdy$$



$$\boldsymbol{R}(z,t) = \frac{1}{\mathcal{N}_{\text{top}}}\int dxdy\ (x\hat{\boldsymbol{x}} + y\hat{\boldsymbol{y}})\ \rho_{\text{top}}(\boldsymbol{r},t)$$



[V. Kravchuk, U. Rößler, J. van den Brink, M. Garst, PRB **102**, 220408(R) (2020)]

- *Skyrmion strings* – topological string-like solitons found in chiral magnets.

- *Object of study* – nonlinear waves and solitons propagating along skyrmion strings. Modes of different symmetries (translational, radially-symmetrical, elliptical, etc.) as well as materials of different magnetic ordering (ferro- and antiferromagnets) will be considered. Influence of spin-polarized current will be investigated.

- *Methods* – (i) phenomenological Landau-Lifshitz formalism for classical description of magnetic media dynamics; (ii) method of collective variables; (iii) multiscale analysis of nonlinear systems; (iv) micromagnetic simulations.

- *Required skills* – basics of mathematical physics (differential equations, variational calculus, spectral problems); basics of computer simulations on CPU or GPU clusters.

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Design and functionalization of 3d magnetic textures

Complex magnetic textures are fun…

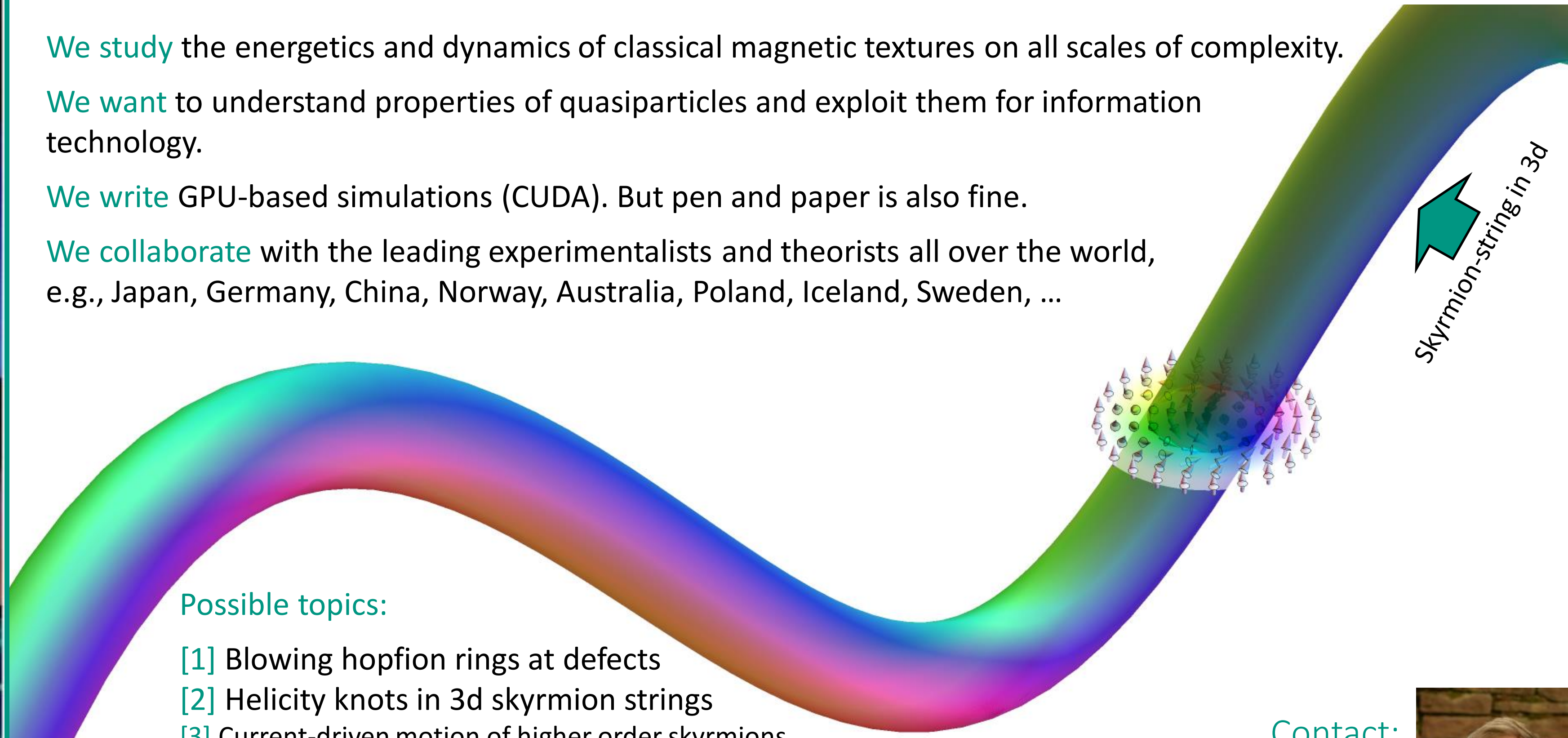
… and an unlimited playground for cutting-edge research.

We study the energetics and dynamics of classical magnetic textures on all scales of complexity.

We want to understand properties of quasiparticles and exploit them for information technology.

We write GPU-based simulations (CUDA). But pen and paper is also fine.

We collaborate with the leading experimentalists and theorists all over the world, e.g., Japan, Germany, China, Norway, Australia, Poland, Iceland, Sweden, …



Possible topics:

[1] Blowing hopfion rings at defects
[2] Helicity knots in 3d skyrmion strings
[3] Current-driven motion of higher order skyrmions
[4] van der Waals interaction of hopfions and skyrmions
[5] Helical phase orientation as new order parameter in novel MRAM devices
[6] Energy barriers for topologically protected skyrmions in itinerant magnets
[7] Skyrmion fluctuations vs scalar spin chirality in "hot" Kagomé magnets
[8] Current-driven motion and pinning of Bloch lines in *realistic* antiskyrmions
[9] Emergent inductance by thermal fluctuations in collinear antiferromagnets
[10] Impact of cubic anisotropies on current-driven dynamics of domain walls and helical phases
[11] The helicity degree of freedom and its role in skyrmion dynamics in frustrated magnets
[12] Hopfions in thermal gradients
[13] Current-driven dynamics of 3d torons and creation from the skyrmion string instability
[14] Emergent inductance by spin-orbit torque
[15] Novel interactions and non-reciprocal effects in materials with C_{3v} symmetry
[16] Pattern formation in skyrmion clusters by dipolar interactions

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