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Revealing nanoscale magnetic correlations in thin films with near-surface SANS

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The discovery of topological protected states in chiral magnets inspired a renaissance in the field of non-collinear magnetism, and led to the identification of several long-wavelength spin objects including skyrmions, merons, solitons, and chiral bobbles. Small angle neutron scattering (SANS) has provided fundamental insights of these magnetic textures in bulk materials, whose associated topological properties are discussed in the context of low-energy information carriers. SANS of such structures in thin films or micro-structured bulk materials is, however, strongly limited by the tiny scattering volume and the prohibitively large background scattering by the substrate and support structures.

In this talk I will discuss near-surface SANS, performed slightly above the critical angle of reflection, as a route to overcome the shortcomings of transmission SANS for extremely small magnetic sample volumes in the thin-film limit [1]. Proof-of-concept measurements performed on bulk MnSi establish equivalent scattering patterns of the helical, conical, and skyrmion lattice phases between transmission and near-surface SANS geometries [2]. Near-surface SANS performed on epitaxial MnSi reveals a phase diagram which differs distinctly from bulk, and comprises of a single-domain, out-of-plane propagating helix with $\lambda = 11.5$ nm in zero-field. Our experimental findings are supported by micromagnetic simulations which depict a magnetic phase diagram dominated by a field-induced unwinding of soliton layers. Field and temperature history provide specific routes for the nucleation of the distinct soliton phases, comprising namely of four-, three-, two-, and single-soliton layers depending on the field strength. This work showcases the applicability of NS-SANS for the study of nano-confined magnetic materials, which would otherwise possess insufficient scattering volumes to be measured in transmission, and provides insights into the role of anisotropy and dimensionality on the phase diagrams of micro-structured bulk materials.

[1] G. L. Causer, J. Appl. Cryst., 58, 1455-1461 (2025)

[2] G. L. Causer et al., J. Appl. Cryst., 56, 26-35 (2023)

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