X-ray studies of dynamic fluctuations in Nano-scaled artificial Spin-Ices

Geometric frustration, in which pair-wise interactions are incompatible with the underlying lattice can be found in many fields. Exploring the effect in bulk crystals is limited by the inability to modify the interactions in a systematic manner. However, arrays of nanoscaled magnetic elements, each acting as a mesospins, allows tailored metamaterials to be created in which to study frustration. The element shape defines the mesospins' anisotropy with the material defining the spin dimensionality and thermal properties. The ability to tailor the lattice, islands and vertex geometry make in such artificial spin ices (ASIs) an attractive field in which to explore fundamental physics. Over several years we have been exploring ASIs by using thermally active Fe/Pd epitaxial 2D-XY film and alloys in which the ordering temperature is tuned through composition [1]. In the thermal regime the collective and local behaviour is associated with individual islands reversing introducing defects which evolve with temperature [2,3]. At higher temperatures, the flipping rate rises with a concomitant loss of long-range order with the system eventually transitioning to a spin-liquid [4]. Significant advances in our understanding of frustration in ASIs have been realized [5-7] but the majority of research is based on direct imaging (MFM or PEEM) of metastable states created which are limited for dynamically evolving systems as acquisition times are necessarily long. In this project you will develop a metrology based on reciprocal space and coherent scattering which has significantly improved spatial and temporal resolution.

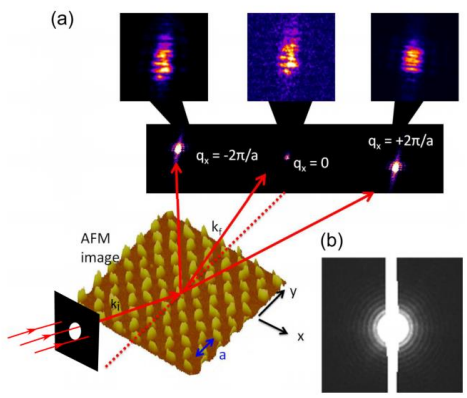

Fig. 1: Schematic of the experimental arrangement [9].

Due to the repeating in-plane array structure sharp peaks are seen in reciprocal space at positions $q_x=2\pi/a$ where a is the array period in the beam direction (fig. 1). Coherent diffraction introduces speckle which arise from disordered phases present in the sample. Quantitative information on the dynamics can be gleaned from intensity-intensity temporal autocorrelation functions and fitted to suitable models accounting for static (non-magnetic) and dynamic (magnetic) signals [8,9].

The PhD project will involve both explorative and targeted investigations in which you will build and develop suitable modelling frameworks to describe more complex artificial spin ice structures with hierarchical complexity; starting with simple Ising chains, then square ices including the Shatki lattice before studying multi-element arrays. You will develop metrologies to explore the temporal evolution using intensity-intensity correlation functions and compare directly x-ray and optical studies with direct space PEEM images. Your results will yield new insights into the role of the lattice in inducing order and provide collaborating evidence from the more myopic microscopy studies. Near criticality, i.e. the ordering temperature T_C, dynamics within the elements will also occur. As these are not correlated, the coherent scattering will be visible at incommensurate positions. This new data have never been explored and will provide an additional XPCS channel which will be compared directly the speckle data.

The project is the result of a long-standing and close collaboration between the group at Warwick [Hase/Bikondoa], and the materials physics group at Uppsala [Hjörvarsson/Kapaklis]. You will be expected to work closely with the Uppsala team and spend time in their research group, participate in joint experiments and design and make new samples. X-ray experiments will be performed at central facilities. The work is highly interdisciplinary, allowing you to develop both experimental and analytical skills.

[1] E. Th. Papaioannou *et al.* J. Phys.: Conden. Mat. 22, 236004 (2010)
[2] V. Kapaklis *et al* Nat. Nanotechnology **9** 514 (2014)
[3] U. B. Arnalds *et al* New J. Phys. **18** 023008 (2016)
[4] U.B. Arnalds *et al* Appl. Phys, Lett. **105** 042409 (2014)
and V. Kapaklis *et al.* New. J. Physics **14** 035009 (2012
[5] E. Östman, *et al* J. Phys.: Condens. Matter **30** 365301 (2018)
[6] E. Östman *et al* Nature Physics **14** ,4, 375-379 (2018)
[7] H. Stopfel *et al* Phys. Rev. B **98** 014435 (2018)
[8] T. Hase *et al* Phys. Rev. B **90** 104403 (2014)
[9] S.A. Morley *et al.* Phys. Rev. B **95** 104422 (2017)