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Diagnostic assessment of model-based iterative reconstruction of magnetisation distributions from electron-optical phase images recorded using off-axis electron holography

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Nanoscale magnetic materials play an important role in modern technology, *e.g.*, in data storage and catalysis. However, characterization of the magnetisation distribution in a sample with nm spatial resolution is a difficult task. The transmission electron microscopy technique of off-axis electron holography enables the recording of the phase shift of an electron wave that has passed through an electron-transparent sample. This phase shift encodes information about electromagnetic potentials within and around the sample (1).

For the reconstruction of magnetisation distributions from electron-optical phase images recorded using off-axis electron holography, either in projection or in three dimensions, we have developed an iterative model-based inversion algorithm and applied it successfully to the characterization of different magnetic structures (2, 3). This algorithm makes use of *a priori* information about the sample, *e.g.*, the positions of magnetised regions, while minimising exchange energy by means of Tikhonov regularisation of first order. The strength of the regularisation is controlled by a parameter λ, which is chosen before reconstruction.

For a full analysis, diagnostic measures can be introduced to assess the quality of the retrieved magnetisation and the influence of a variety of reconstruction parameters.

In particular, an L-curve analysis (4) can be used as a heuristic method to find the optimal regularisation strength to achieve an optimal trade-off between compliance with the experimental measurements (which always contain recording noise and can be affected by artefacts) and with the specified *a priori* information.

The influence of the chosen regularisation strength on the reconstructed magnetisation distribution can then be assessed by means of optimal estimation linear diagnostics (5) which provide a "gain matrix" that describes the propagation of phase noise to the reconstructed magnetisation, as well as an "averaging kernel", which provides a measure of the resolution of the reconstruction.

Approaches that can be used to tackle other challenges, including the presence of magnetised regions outside of the field of view, phase ramps, phase offsets and errors in the determination of the edges of the magnetised regions will be discussed.

References:

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Fig. 1

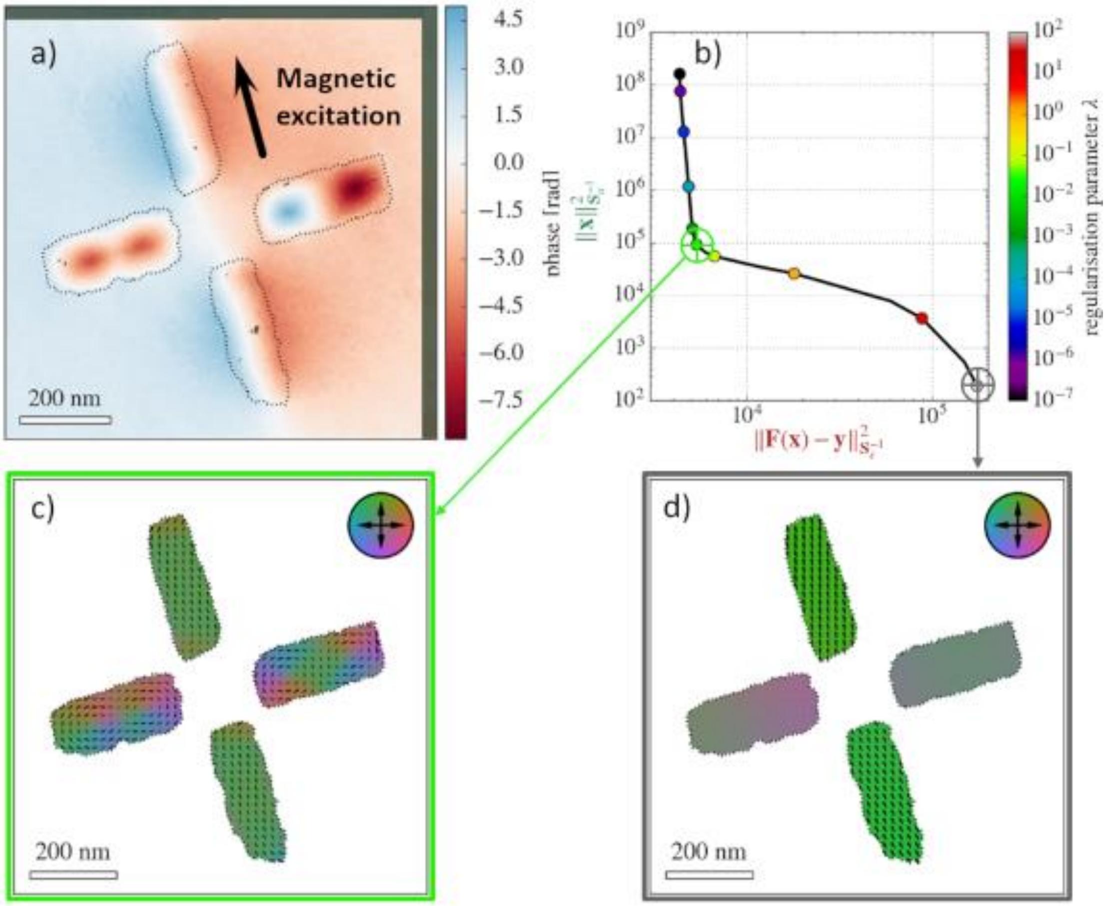

Figure 1: a) Magnetic phase image of a lithographic Co pattern. **b)** L-curve plot analysing the trade-off between compliance with measurements (abscissa) and *a priori* information (ordinate). **c)** Reconstruction for an optimal regularisation parameter. **d)** Reconstruction for overtuned regularisation, with features smoothed away.