# Supplementary Notes

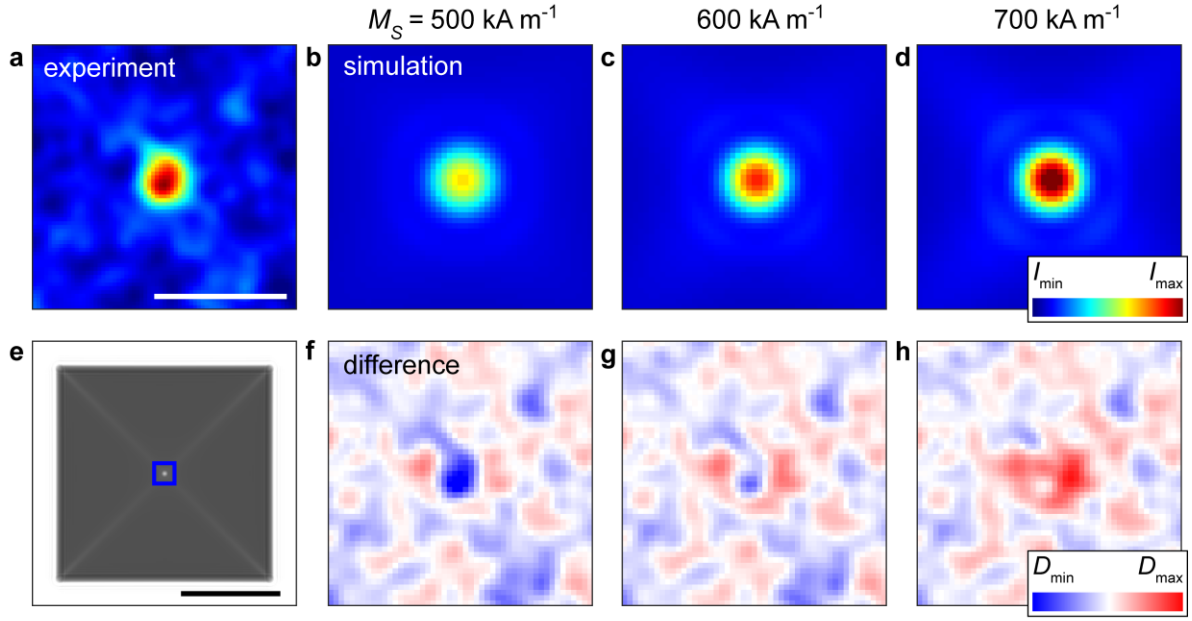
## Supplementary Note 1

To evaluate the saturation magnetization of the magnetic material, we simulate Fresnel images based on micromagnetic simulations and compare the results to the measured Fresnel image in Fig. 4a. We calculate the magnetic configuration in the nanostructure using the MuMax3[1] software package. To this end, we set up a simulation in a volume of $2100 \times 2100 \times 26\ \mathrm{nm}^3$ with $512 \times 512 \times 8$ cells. We choose an exchange stiffness[2] of $A_{\mathrm{ex}} = 1.1 \cdot 10^{-11}\ \mathrm{J\ m^{-1}}$ and calculate the magnetic ground state for various values of the saturation magnetization $M_{\mathrm{S}}$.

Based on the magnetization integrated along the z-axis, we calculate the Aharonov-Bohm phase acquired by the electron passing through the sample[3]. This phase can be used to simulate a Fresnel micrograph via a multiplication with the contrast transfer function of the microscope in momentum space[4]. For the image simulation, we used the same imaging conditions as in Fig. 4a, i.e., a defocus value of $\Delta f = 600\ \mu\mathrm{m}$ and a beam divergence of $\theta_{\mathrm{c}} = 10\ \mu\mathrm{rad}$. An electron transmission through the permalloy of 0.32 was deduced from an in-focus micrograph.

Supplementary Figure 1 shows a close-up region of the experimental Fresnel image (a), simulations for three different saturation magnetizations (b-d) and difference images (f-h). The simulated image for the entire square is shown in (e). Best agreement of experiment and simulation is obtained for $M_{\mathrm{S}} = 600\ \mathrm{kA\ m^{-1}}$, for which the residual difference (f-h) in the region of the vortex feature is at the level of the noise.

## Supplementary Figures




Supplementary Figure 1: Determination of the saturation magnetization by a comparison of simulated and experimental Fresnel images. (a) Detailed view of the Fresnel micrograph in Fig. 4a (scale bar: 100 nm). A Gaussian filter with standard deviation $\sigma = 5.8\ \mathrm{nm}$ was applied. (b-d) Identical image section as in (a) for simulated Fresnel images based on micromagnetic simulations using the saturation magnetization stated above the image. (e) Total view of a simulated Fresnel image, here using the example of $M_S = 600\ \mathrm{kA\ m^{-1}}$ (scale bar: 1000 nm). Blue square corresponds to the region shown in (b-d). (f-h) Difference images between the experimental micrograph and the simulated images.

## Supplementary References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3. Mansuripur, M. Computation of electron-diffraction patterns in Lorentz electron microscopy of thin magnetic films. *J. Appl. Phys.* **69**, 2455–2464 (1991).

4. De Graef, M. 2. Lorentz microscopy: Theoretical basis and image simulations. in *Magnetic Imaging and its Application to Materials. Experimental Methods in the Physical Sciences* (eds. De Graef, M. & Zhu, Y.) **36**, 27–67 (Academic Press, 2001).