Science Advances
AAAS

# Supplementary Materials for

## Real-space observation of fluctuating antiferromagnetic domains

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*Sci. Adv.* **8**, eabj9493 (2022)
DOI: 10.1126/sciadv.abj9493

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Supplementary Text
Fig. S1
Legends for movies S1 to S3

**Other Supplementary Material for this manuscript includes the following:**

Movies S1 to S3

## Supplementary Text

Spatial resolution

The spatial resolution of the setup utilizing the incident beam focused by Fresnel zone plate (FZP) was determined experimentally. Figs. S1 A–D show domain wall images obtained for two different distances between the sample and the FZP. The magnetic domain wall is imaged as a dark central line surrounded by the interference fringes, see panels C and D. We define the spatial resolution as the distance between the first-order bright fringes. This distance sets the size of the smallest resolvable domain (for example, in a stripe domain pattern). Figs. S1 E and F show cuts through the domain walls (intensity versus position) along the red lines in C and D. The obtained spatial resolutions are 3.6 μm and 2.1 μm, respectively. They vary slightly across the image area, possibly affected by the domain wall direction, its position within the image, and by the interference of nearby domain wall signals. The intrinsic domain wall width is expected to be on a sub-micron scale, and its effects can be neglected. The images in Figs. 3-5 in the main text and all the movies in this paper were obtained using the setup utilized in Fig. S1 A. With decreasing distance, the FZP focal region is moving closer to the sample, the beam's footprint on the sample becomes smaller, and the experimentally obtained spatial resolution improves. As the beam diameter at the sample position is reduced from 80 μm to 15 μm, the resolution changes from 5 μm to 2 μm. Smaller sample to FZP distances are possible, but technical limitations prevented us from reaching them in this experiment. In bulk samples, the ultimate achievable resolution cannot significantly exceed the x-ray penetration depth (μ), because the width of the domain wall image cannot be smaller than the projection of the portion of the domain wall that is protruding length μ into the sample. The values of μ lie in the 100-200 nm range in typical *3d*-element magnets at their respective *L* edge x-ray energies. These values set the scale of the achievable resolution. In thin films, the film thickness plays the role of μ. Given the x-ray intensities observed in our work, we estimate that the films as thin as several tens of nm should produce a measurable signal. The intrinsic resolution of the FZP is not a limiting factor because it is set by the outer zone width, which could be smaller than 20 nm. We therefore speculate that the spatial resolutions as small as several tens of nm might be achievable in thin films. Many other factors, such as the incident x-ray beam coherence, divergence, *etc*. may also affect the achievable resolution in nontrivial manner. Therefore, the best achievable resolution of the method must be determined experimentally. This is the subject of future work.

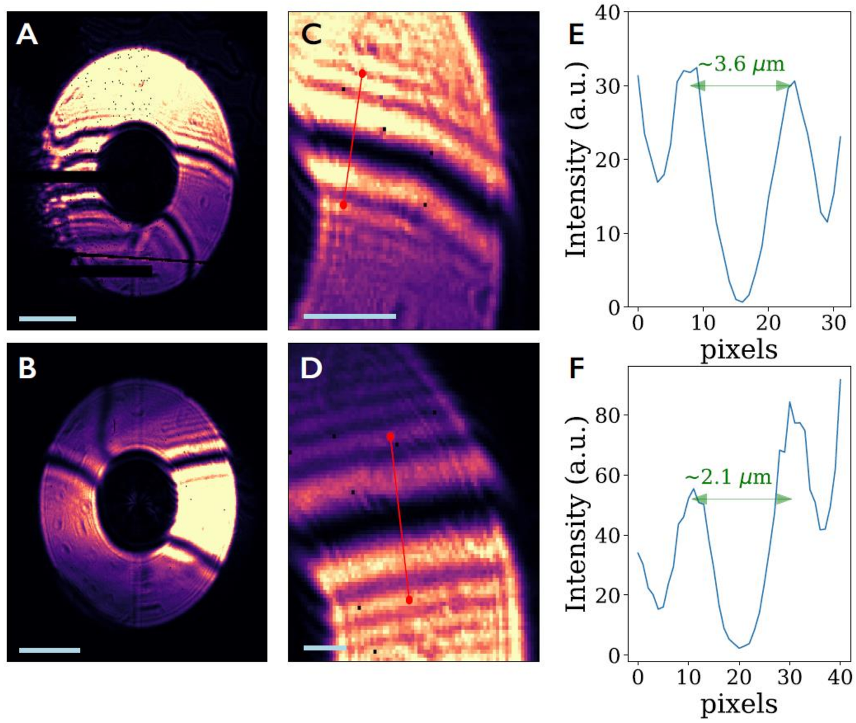


**Fig. S1.**

**Spatial Resolution. (A)**, **(B)** Domain wall images for two different sample to FZP distances. **(C)**, **(D)** Image blowups showing one domain wall for **(A)** and **(B)**, respectively. **(E)**, **(F)** Cuts through the domain walls (intensity vs. position) along the red lines in **(C)** and **(D)**, respectively. Scale bars are: **(A)** 10 µm, **(B)**, **(C)** 5 µm, **(D)** 1 µm.

**All Movies.**

The frame capture time is $5.75\times10^{-2}$ s and the interval between two consecutive frames is 0.195 s.

**Movie S1.**

A 5000-frame movie, corresponding to 16 min 15 s real time. The movie is taken at the scattering vector of the collinear state, $Q_C$ = (0, 0, 1.5). The temperature $T$ = 67.73 K. Each frame is stretched vertically by the factor $1/\sin(\theta) = 1.27$ to correct for the beam footprint size effect and to ensure uniform magnification.

**Movie S2.**

Motion of the bulging domain wall in the collinear state, to supplement Fig. 3(a). The temperature is $T$ = 67.73 K.

**Movie S3.**

Fluctuating patterns in the helical state at $T$ = 68.5 K. Each frame is stretched vertically by the factor $1/\sin(\theta) = 1.41$ to correct for the beam footprint size effect and to ensure uniform magnification. Supplements Fig. 5.