Time-resolved soft X-ray microscopy of magnetic nanostructures at the P04 beamline of PETRA III

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1. Motivation

Time-resolved imaging of nanoscale magnetic systems is a powerful tool motivated by the following main goals:

- Study magnetism directly in space and time at its fundamental ultra-fast **time-** and ultra-small **length-scales**.
- Increase performance (**data-density** and **access time**) as well as stability of **magnetic data storage devices**.
- Research on magnetic data transport and **magnetic logic devices** for future **spintronic** computer concepts.
- Capture and understand the **destruction and recovery of domain patterns** in real time.

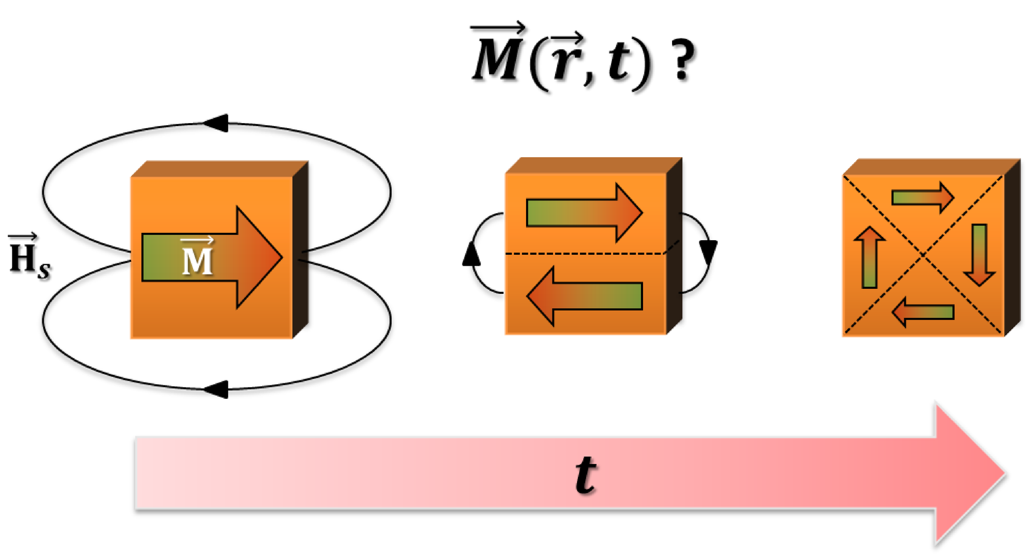

Figure 1: *The creation of domains reduces the stray field $\vec{H}_s$ of small magnetic structures. With our setup it is possible to capture the dynamics of domain formation to the magnetic ground state out of a non-equilibrium magnetization state via measuring $\vec{M}(\vec{r},t)$.*

2. Experimental setup

2.1 Time-resolved magnetic full-field transmission X-ray microscope (TR-MTXM)

- A mobile time-resolved magnetic full-field transmission X-ray microscope (TR-MTXM) for the **soft X-ray beamline P04 at PETRA III** has been set up [3, 2].
- Flat-top illumination field of 20 µm diameter generated by **grating condenser** for Köhler-like illumination [5].
- Sample plane imaged by **micro zone plate** with outermost zone width of 50 nm (fig. 2).
- Magnetic samples can be pumped by a **picosecond pulse generator** (pulse duration 200 ps, peak amplitude 80 mT) or a **synchronized femtosecond laser system** (pulse duration 300 fs) at the revolution frequency of the synchrotron (130 kHz) [3, 2].
- Unpumped probe pulses are separable by an in-house developed **fast gateable X-ray detector**.
- **Magnetic reset pulses** of up to 2 µs pulse duration can be applied by a coil operated at 130 kHz.
- A movable permanent magnet is available in order to apply **adjustable external bias fields**.

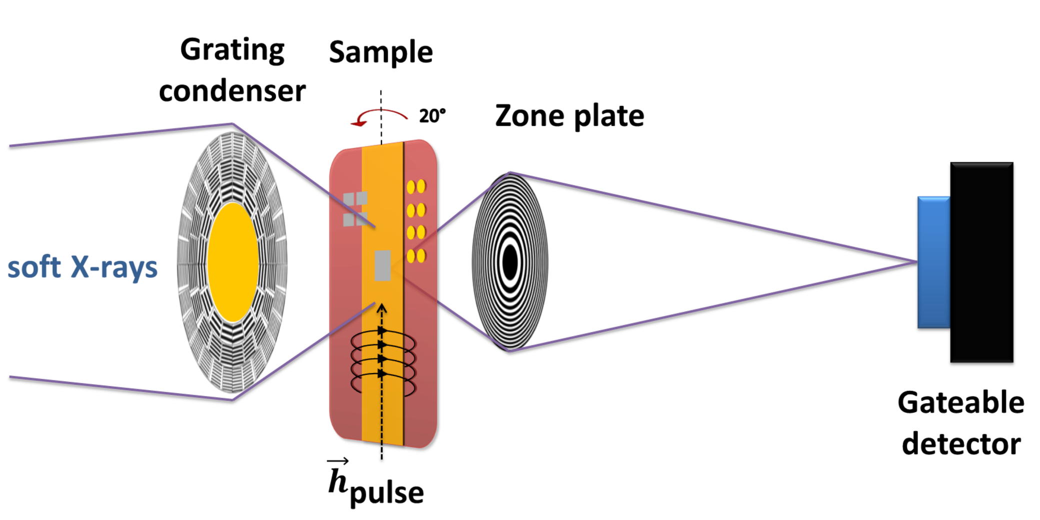

Figure 2: *Setup of the time-resolved magnetic transmission soft X-ray microscope consisting of a grating condenser with gold central stop and a micro zone plate. The time resolution is achieved by applying pump ($\vec{h}_{pulse}$), probe and reset pulses with controllable low-jitter delays [2].*

3. Results

3.1 Magnetic transmission X-ray microscope

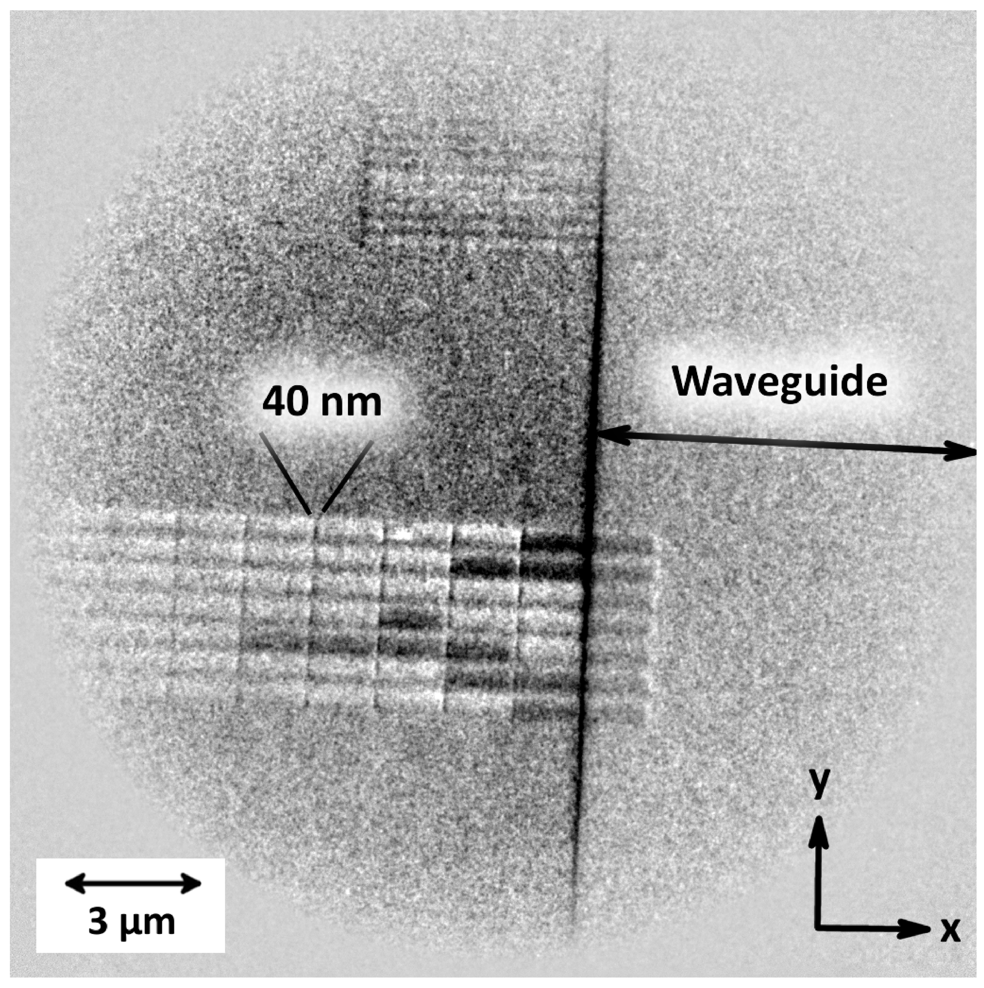

Figure 3: *X-ray magnetic circular dichroism (XMCD) image mapping the magnetization of a permalloy ($Ni_{80}Fe_{20}$) array consisting of 1.3 µm × 0.3 µm × 0.01 µm elements separated by ≈ 40 nm at the Ni L_3 edge (853 eV). A spatial resolution of ≈ 60 nm has been achieved. For each helicity the detector was exposed for 150 s [4].*

3.2 Time-resolved magnetic studies

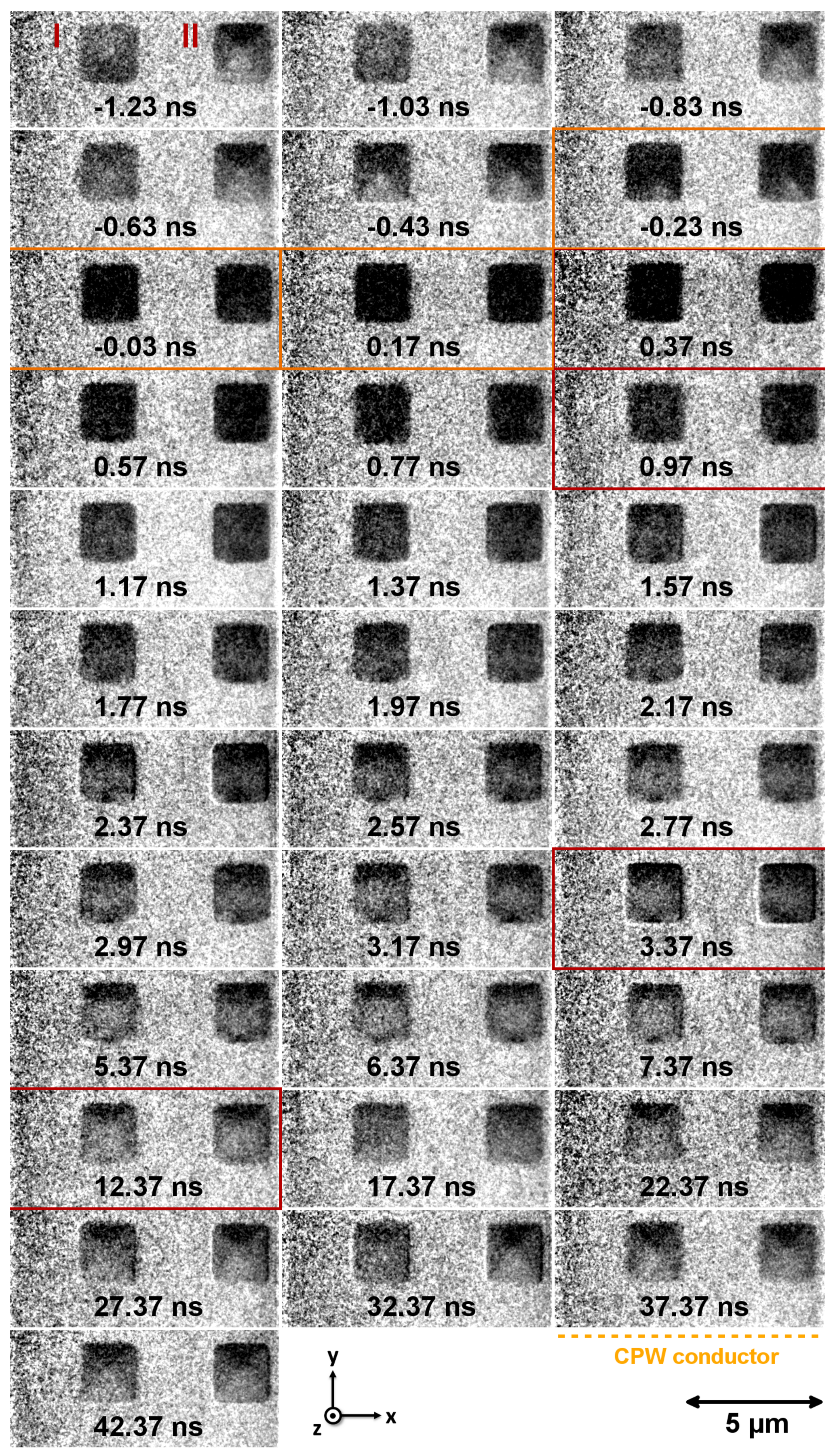

Figure 4: *Time-resolved XMCD movie of magnetization alignment and subsequent domain pattern recovery of 2 µm × 2 µm × 0.03 µm permalloy squares. The squares are stimulated by the magnetic field pulse (orange marked frames) of the waveguide. For each frame the detector was exposed for 180 s at both helicities [4, 1].*

Time-resolved measurements of permalloy squares with a highly out-of-equilibrium magnetization configuration (fig. 4 and 5) [4, 2, 1] reveal the **dynamics of domain pattern destruction and recovery** as well as a **reproducible, unusually fast vortex core kick-out** (fig. 6 and tab. 1).

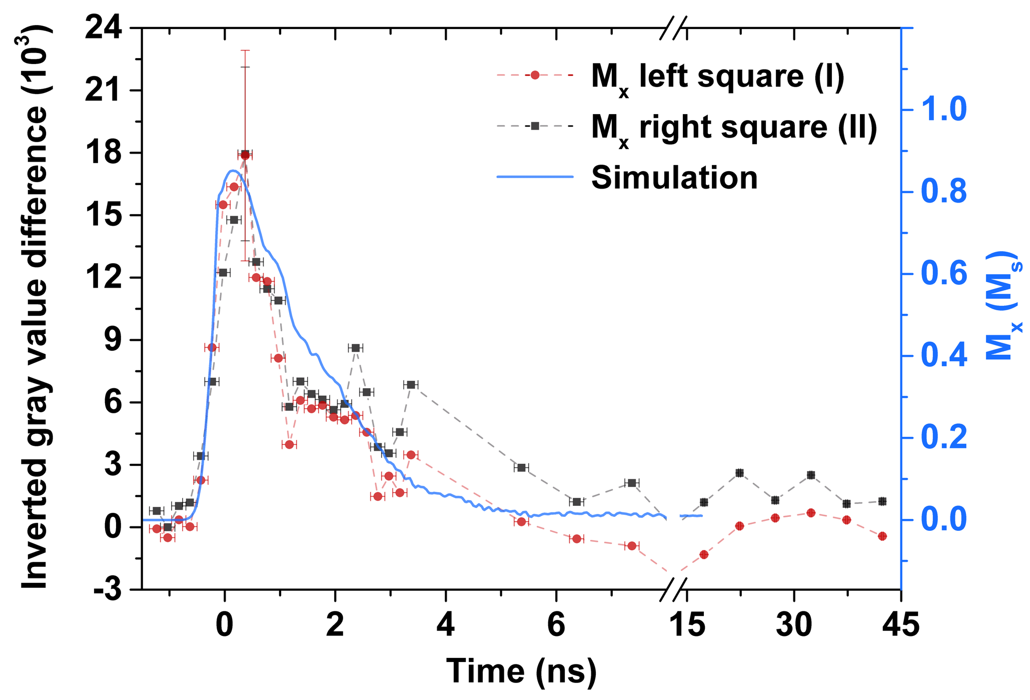

Figure 5: *Gray value of the XMCD contrast images corresponding to the magnetization component M_x in the permalloy squares (1 and 2) on the CPW conductor in fig. 4 along with a micromagnetic simulation using* Nmag *[4, 1].*

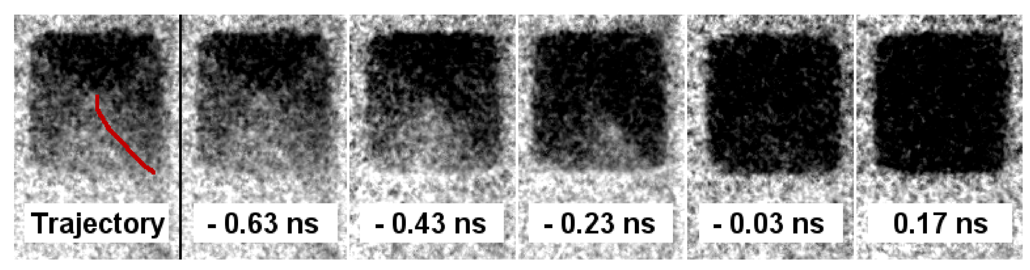

Figure 6: *Magnetization dynamics of permalloy square II in fig. 4 on the rising edge of the magnetic field pulse revealing the trajectory during kick-out of the vortex core [4, 1].*

Time t (ps)	Position x (nm)	Position y (nm)	Velocity v_x (km/s)	Velocity $-v_y$ (km/s)
–630	0	158	0.1 ± 0.3	1.1 ± 1.0
–430	20	–59	0.4 ± 0.2	1.2 ± 0.6
–230	178	–317	1.8 ± 0.8	2.1 ± 1.0
–30	733	–911	1.7 ± 0.8	1.7 ± 0.8
170	581	–990	0.6 ± 0.6	0.4 ± 0.5

Table 1: *Positions and velocities of the vortex core in fig. 6. The temporal uncertainty is dominated by the jitter of 130 ps and the spatial inaccuracy by the corresponding length of 40 nm (two pixel) [4, 1].*

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References

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