Imaging sub-ns spin dynamics in magnetic nanostructures with Magnetic Transmission X-ray microscopy

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Outline

- challenges
- experiment
  - magnetic transmission X-ray microscopy (full field)
  - stroboscopic pump-and-probe
- spin dynamics in PY nanoelements
  - pumping w/ micro-coils
  - pumping w/ striplines
- conclusion & outlook

Characteristic length and time scales

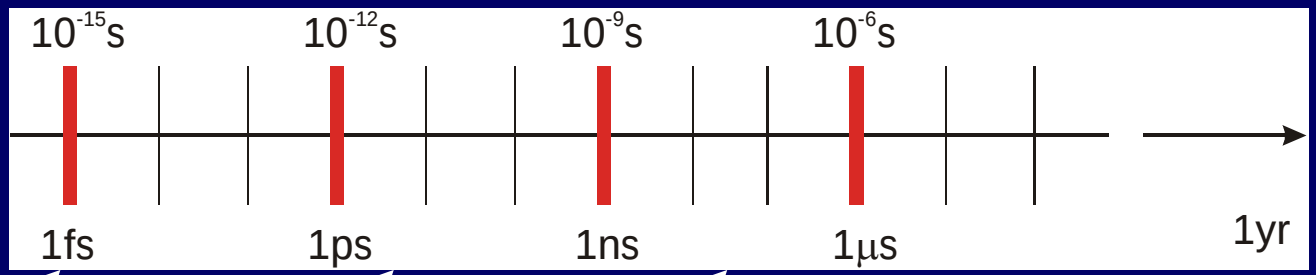
- Nanomagnetism
  - magnetic exchange lengths

$$l_K = \sqrt{A/K},\ l_S = \sqrt{2\mu_0 A / J_S^2}$$

e.g. permalloy

$$l_K = 161\,nm,\ l_S = 5.7\,nm$$

  - magnetic domains and domain walls
- Magnetisation dynamics



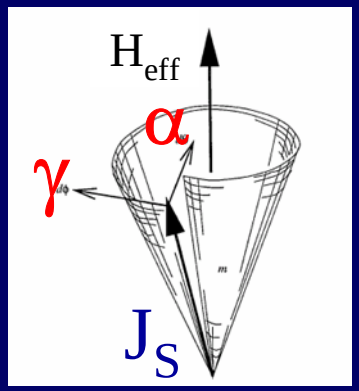
spin fluctuation
exchange interaction

precession
relaxation

domain wall motion
thermal activation

Spin dynamics and micromagnetism

Landau-Lifshitz Gilbert equation of motion



$$\frac{d\vec{J}_S}{dt} = \gamma\left[\vec{J}_S \times \vec{H}_{eff}\right] - \frac{\alpha}{J_S}\left[\vec{J}_S \times \dot{\vec{J}}_S\right]$$

γ precession α damping

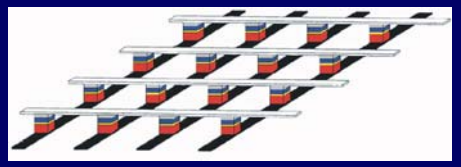
- anisotropy
- morphology
- geometry

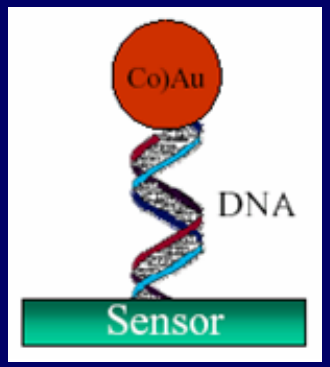
$$\vec{H}_{eff} = -\frac{1}{M}\frac{\delta g}{\delta \vec{m}} \text{ and } g = A(\nabla \vec{m})^2 + F_{an}(\vec{m}) - \vec{H}_{ex}\cdot\vec{J} - \tfrac{1}{2}\vec{H}_s\cdot\vec{J}$$

exchange anisotropy ext. field stray field

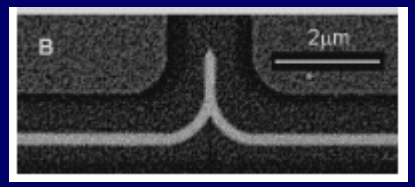
Technological relevance

- Magnetism on nanometer length scales
  - Spintronics
  - Data Storage
  - Sensors
  - Actuators
  - Biomagnetism



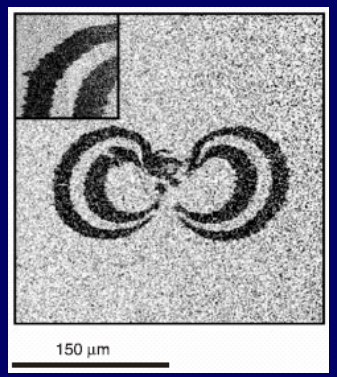


from S.X.Wang Stanford CA

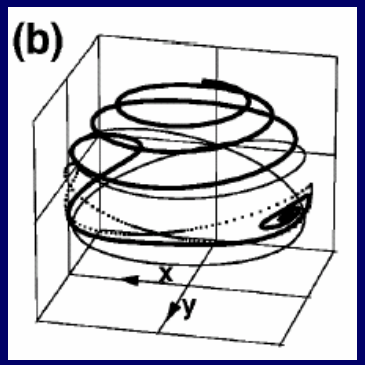


from R.W. Cowburn, Durham UK

- Ultra fast switching schemes in recording media
  - precessional switching

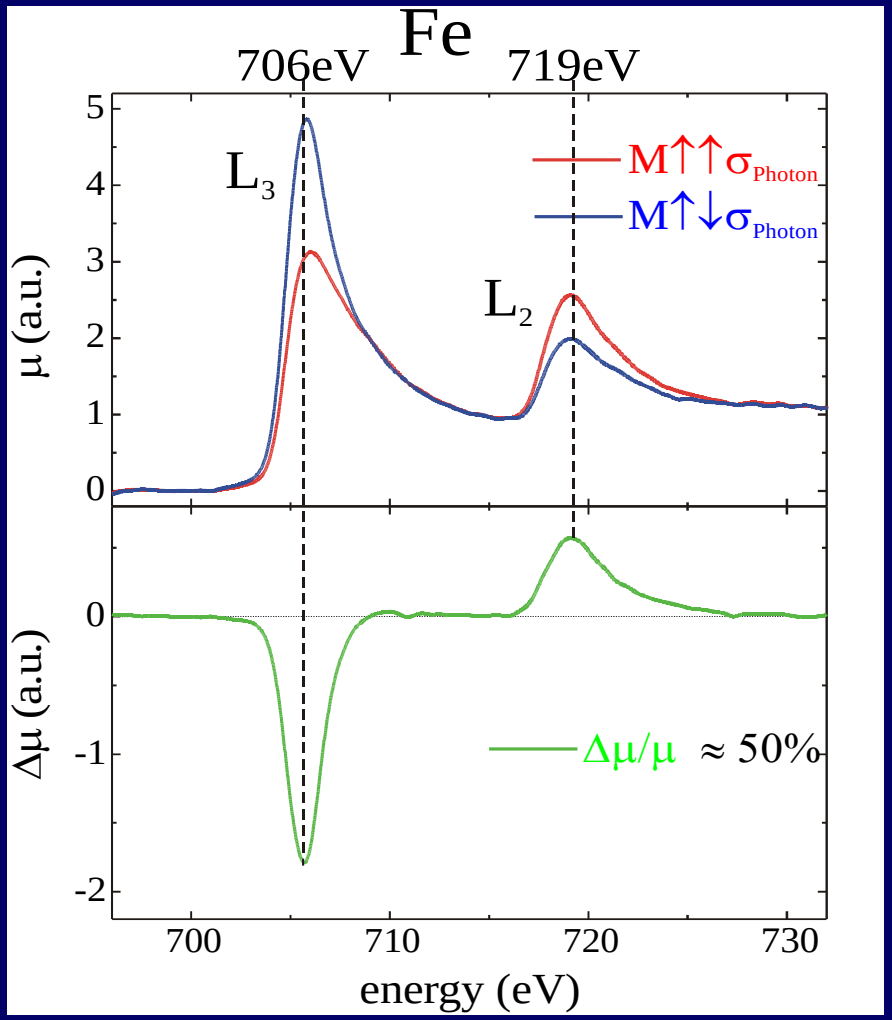


Ch.H. Back, et al., Science 1999



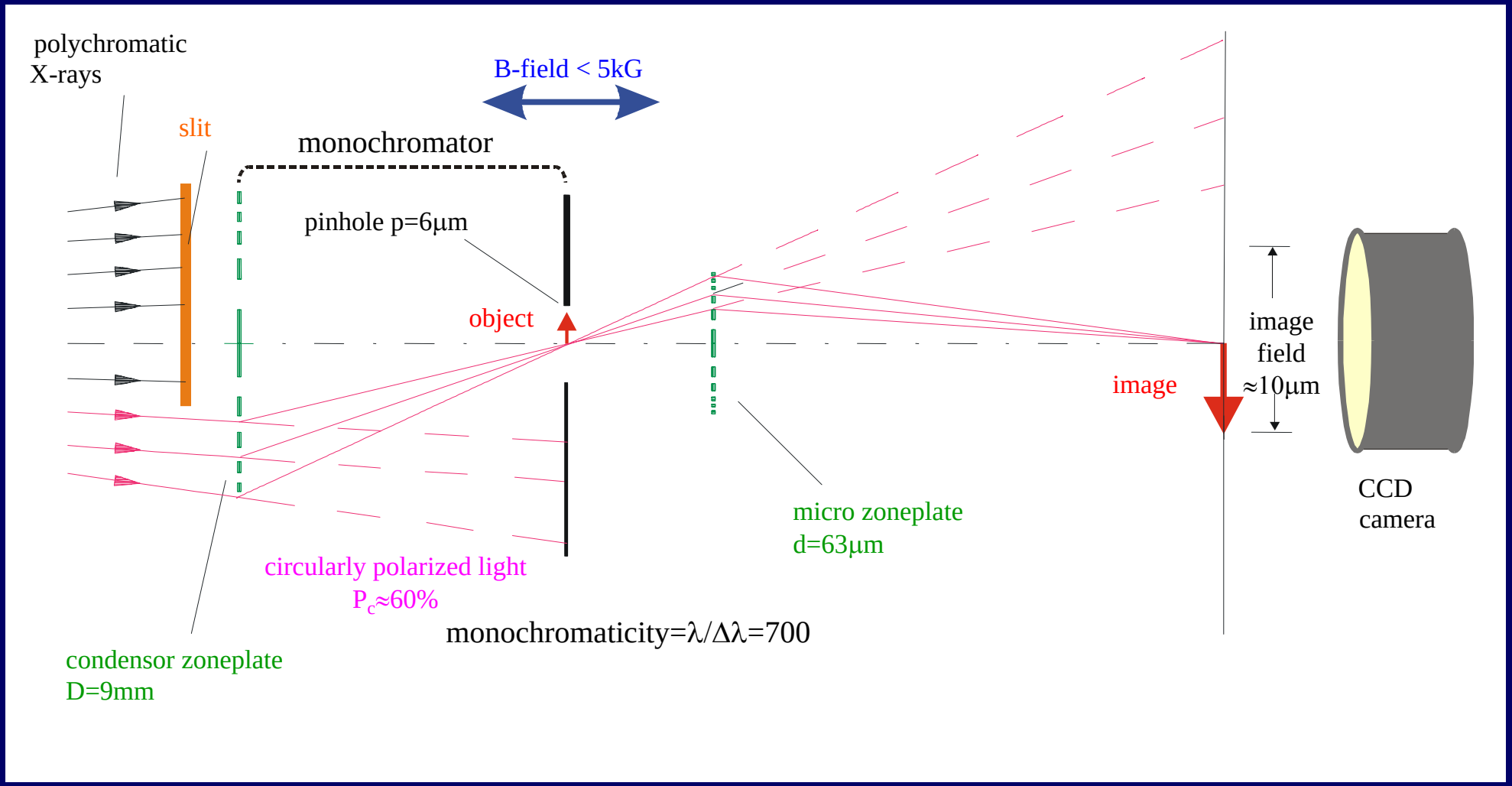
Y. Acreman, et al.,APL 2001

X-MCD at L_3 and L_2 edges

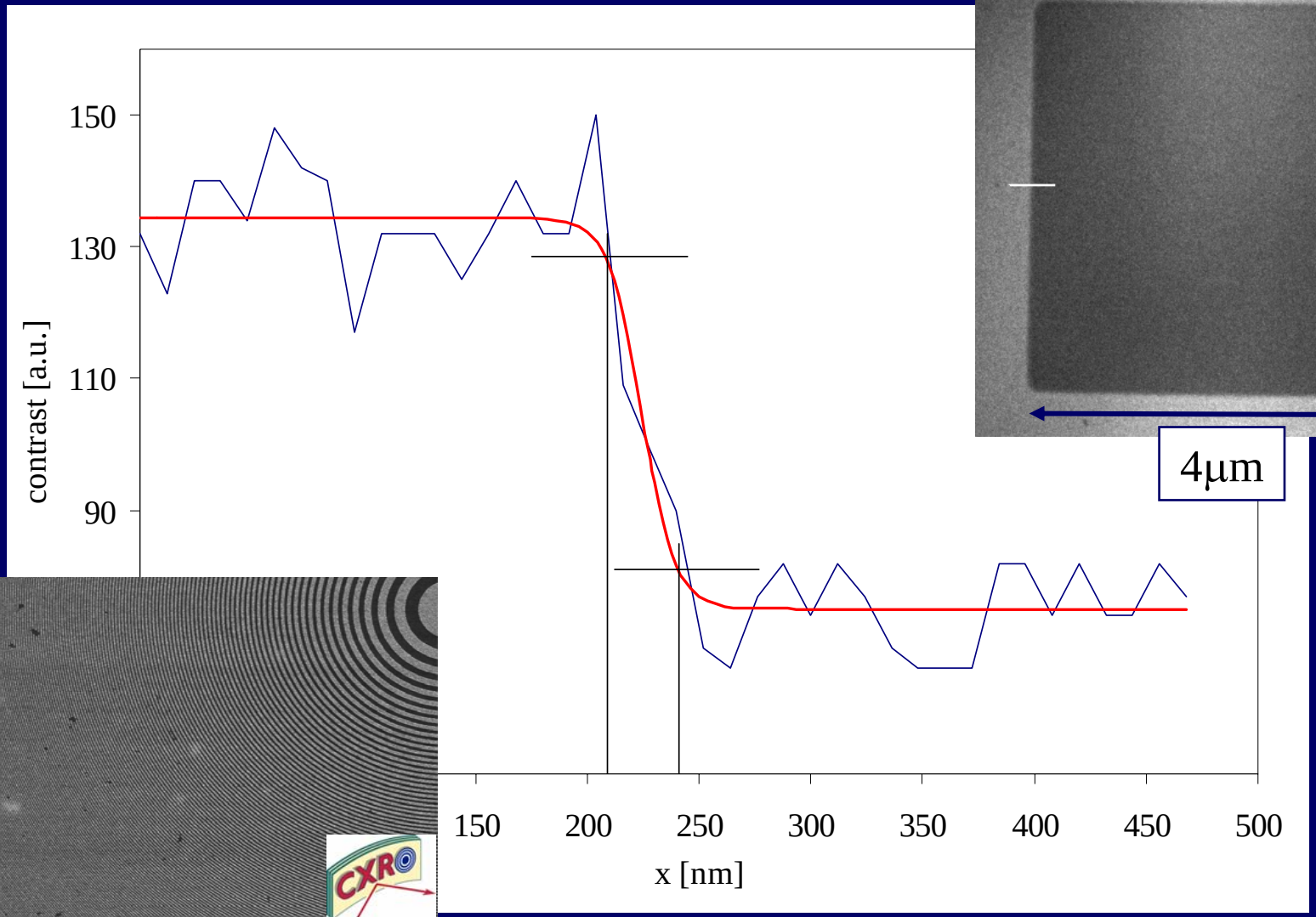


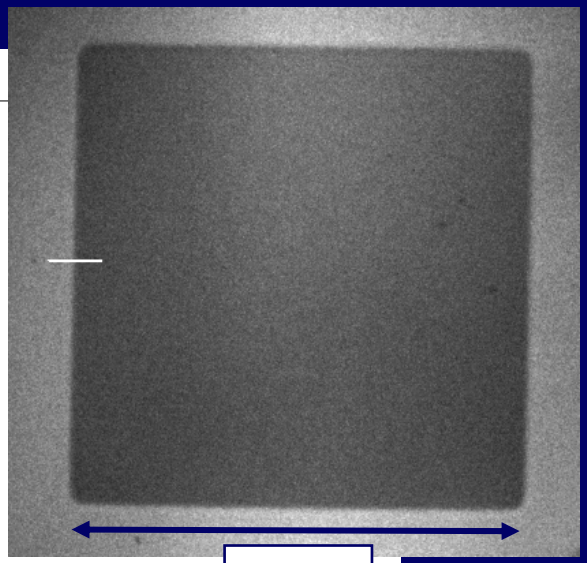
- element-specific
- huge magnetic contrast
- $\underline{M} \cdot \underline{\sigma}_{Photon}$
- Spin-orbit information

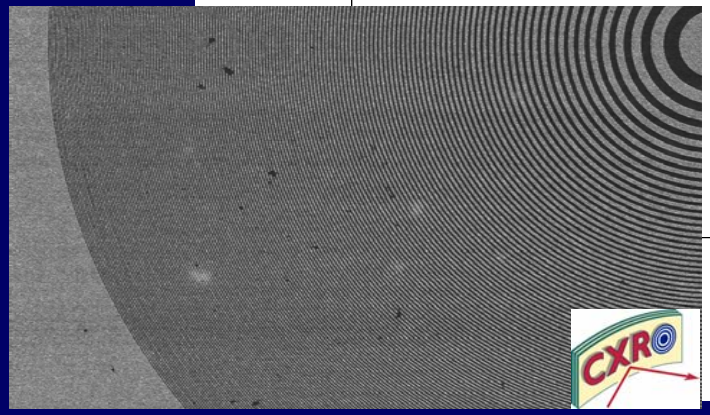
Magnetic Transmission X-ray-microscopy



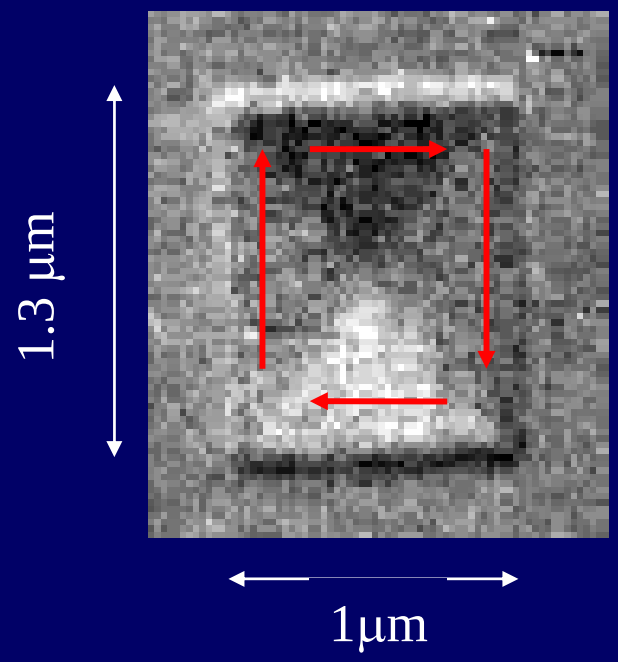
Lateral resolution

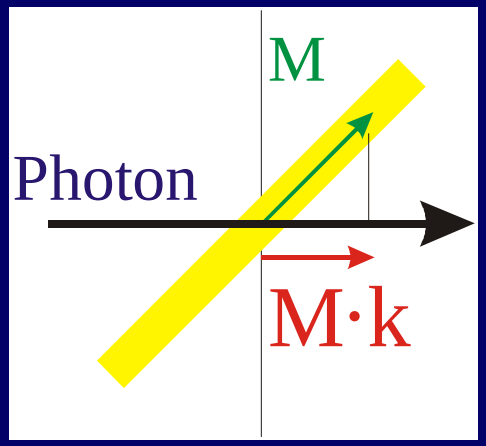






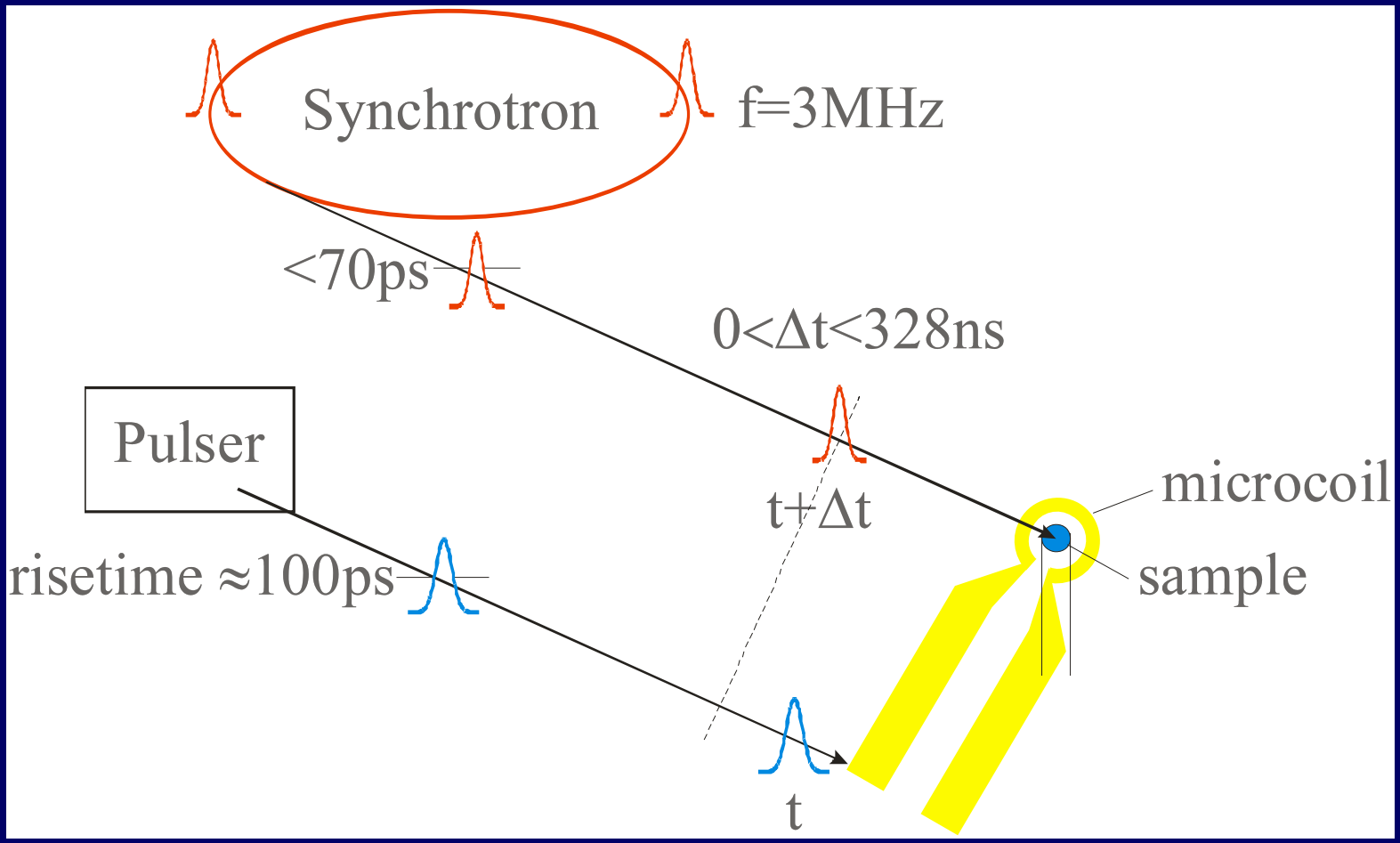
Static domain structure



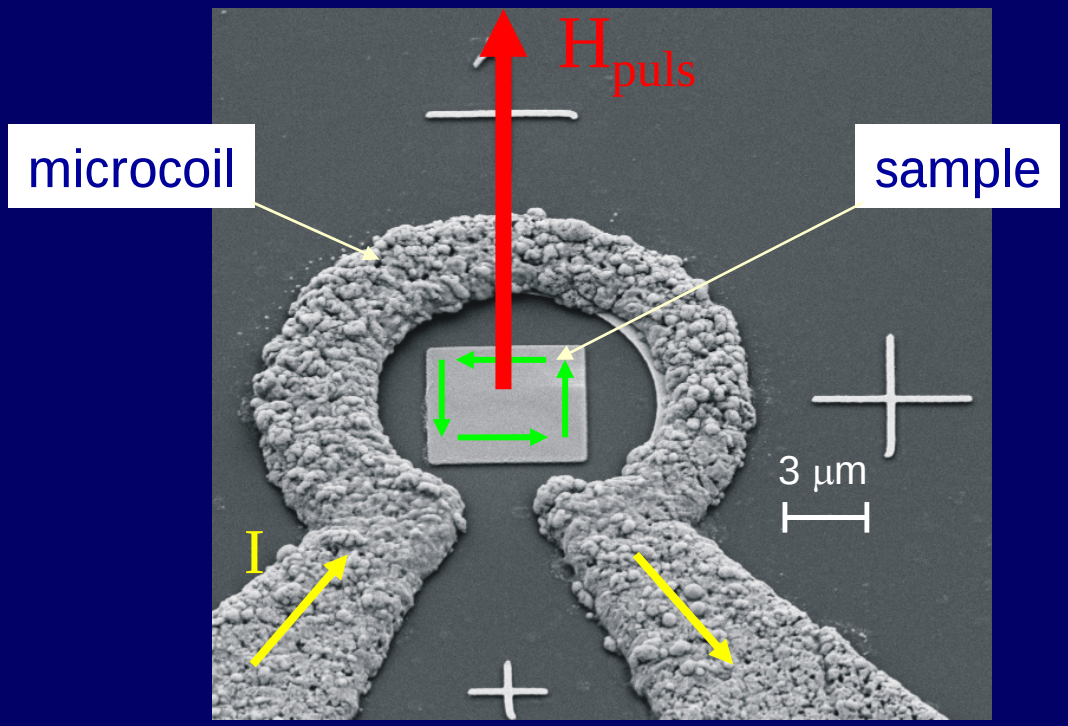


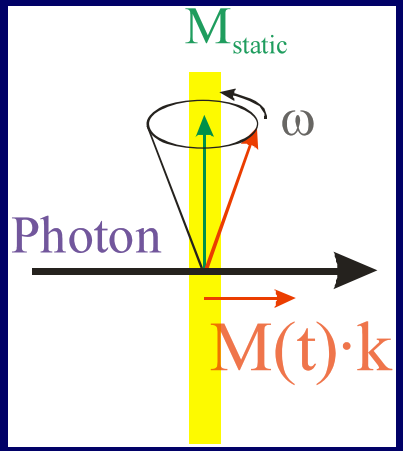
PY: $Ni_{80}Fe_{20}$ (50 nm) @ Ni L_3 edge

Stroboscopic pump-and-probe imaging



Pumping with microcoils

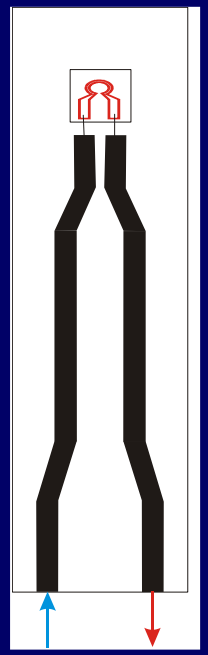


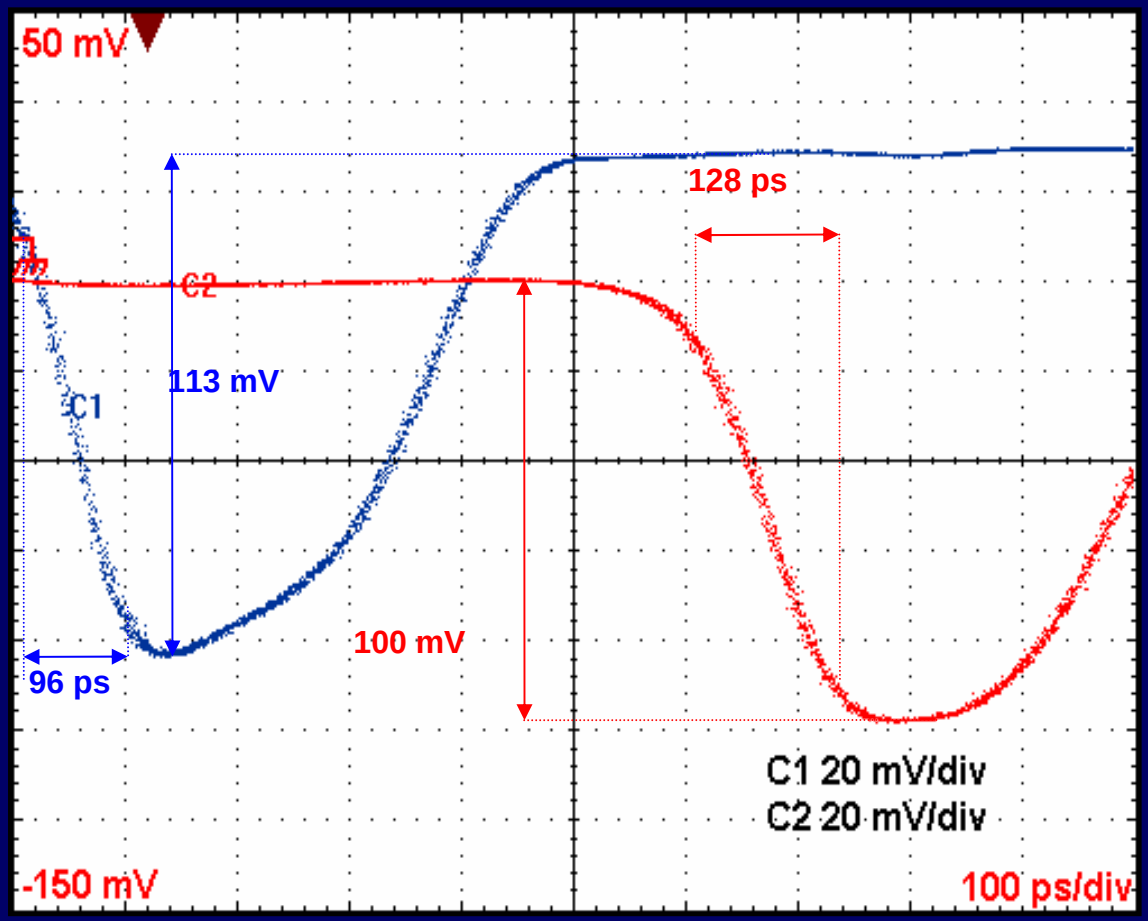


- initial field pulse perpendicular to the plane of the sample

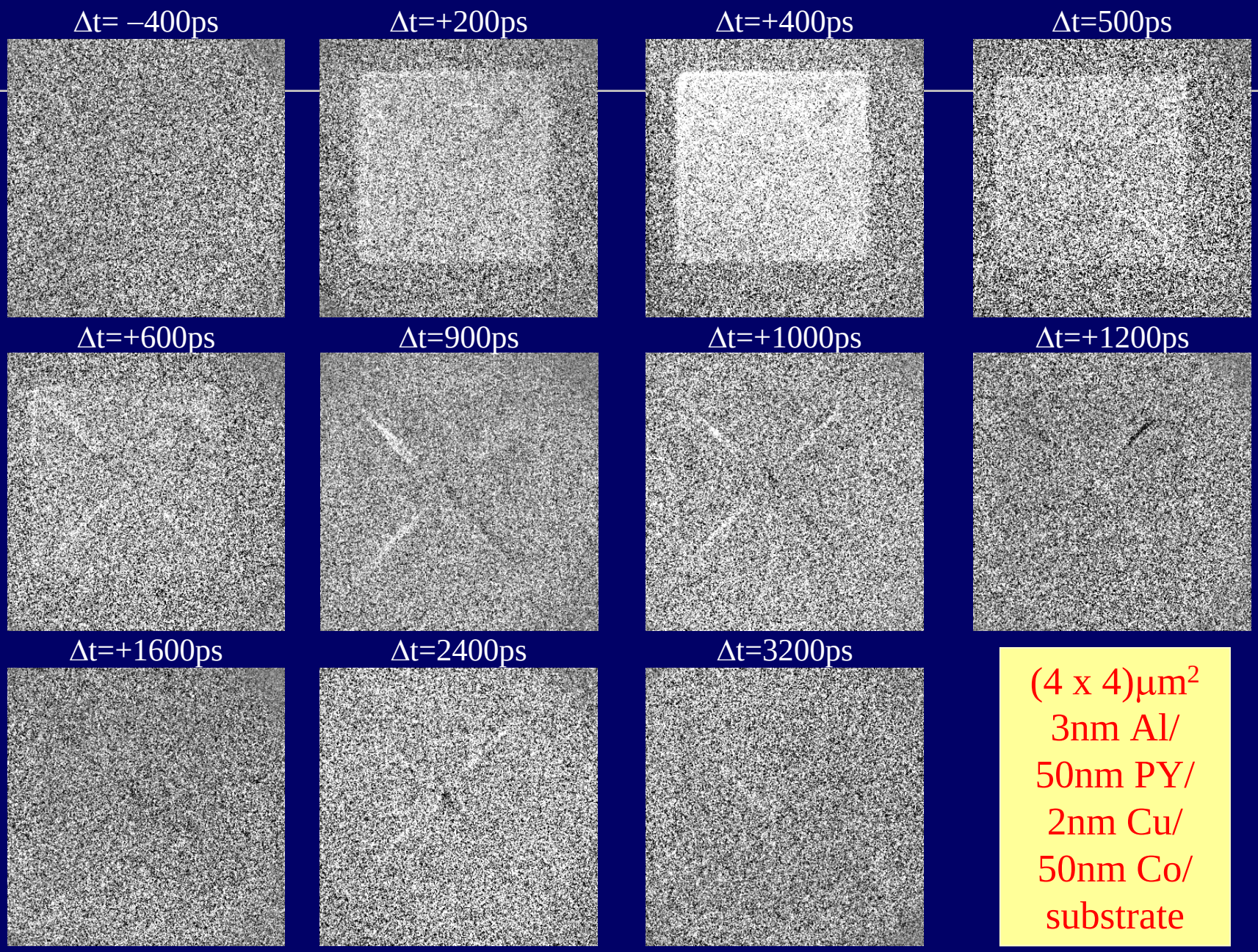
Properties of the magnetic pulses

V_{max}: 15V
I_{max}: 300mA
pulse width: 0.2-2ns
rep.freq.: up to 25MHz
rise time: <100ps





Observation of local spin dynamics

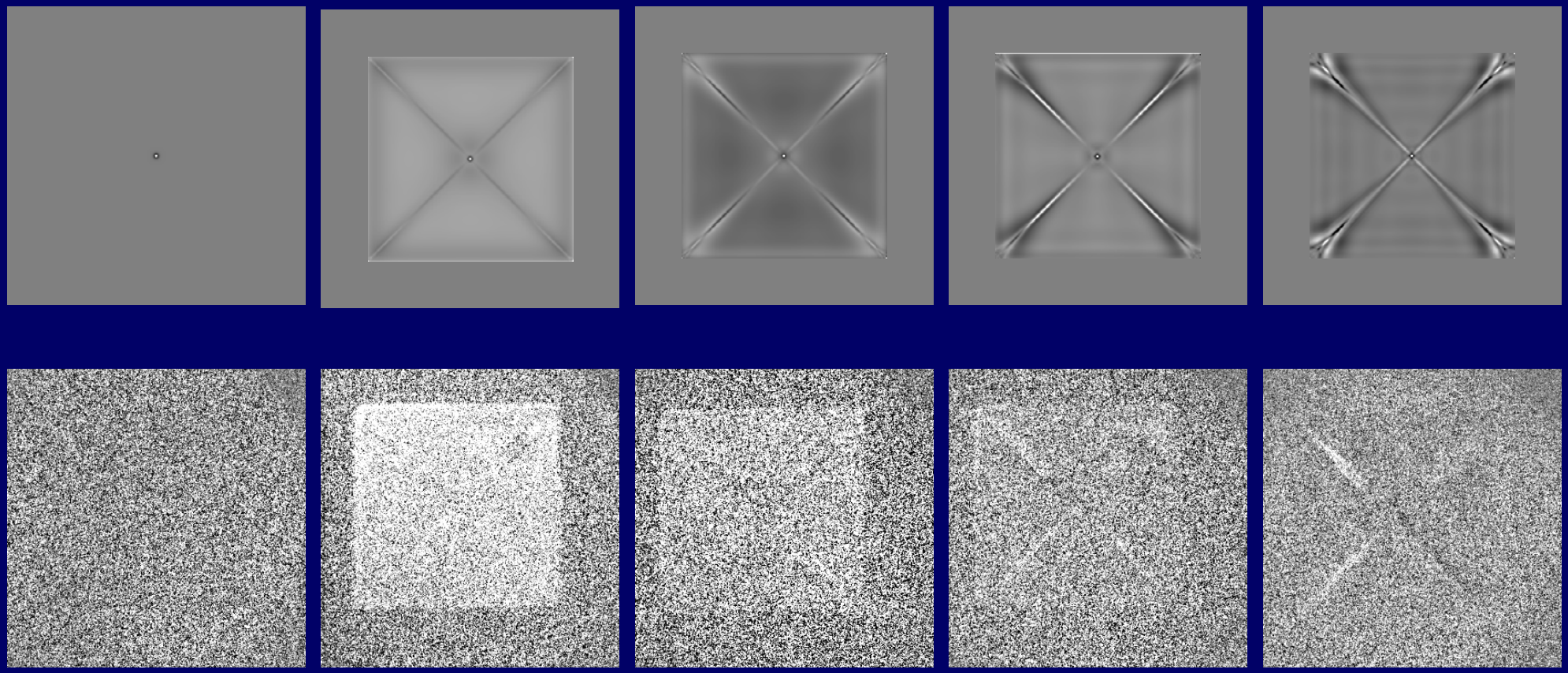


(4 x 4)μm²
3nm Al/
50nm PY/
2nm Cu/
50nm Co/
substrate

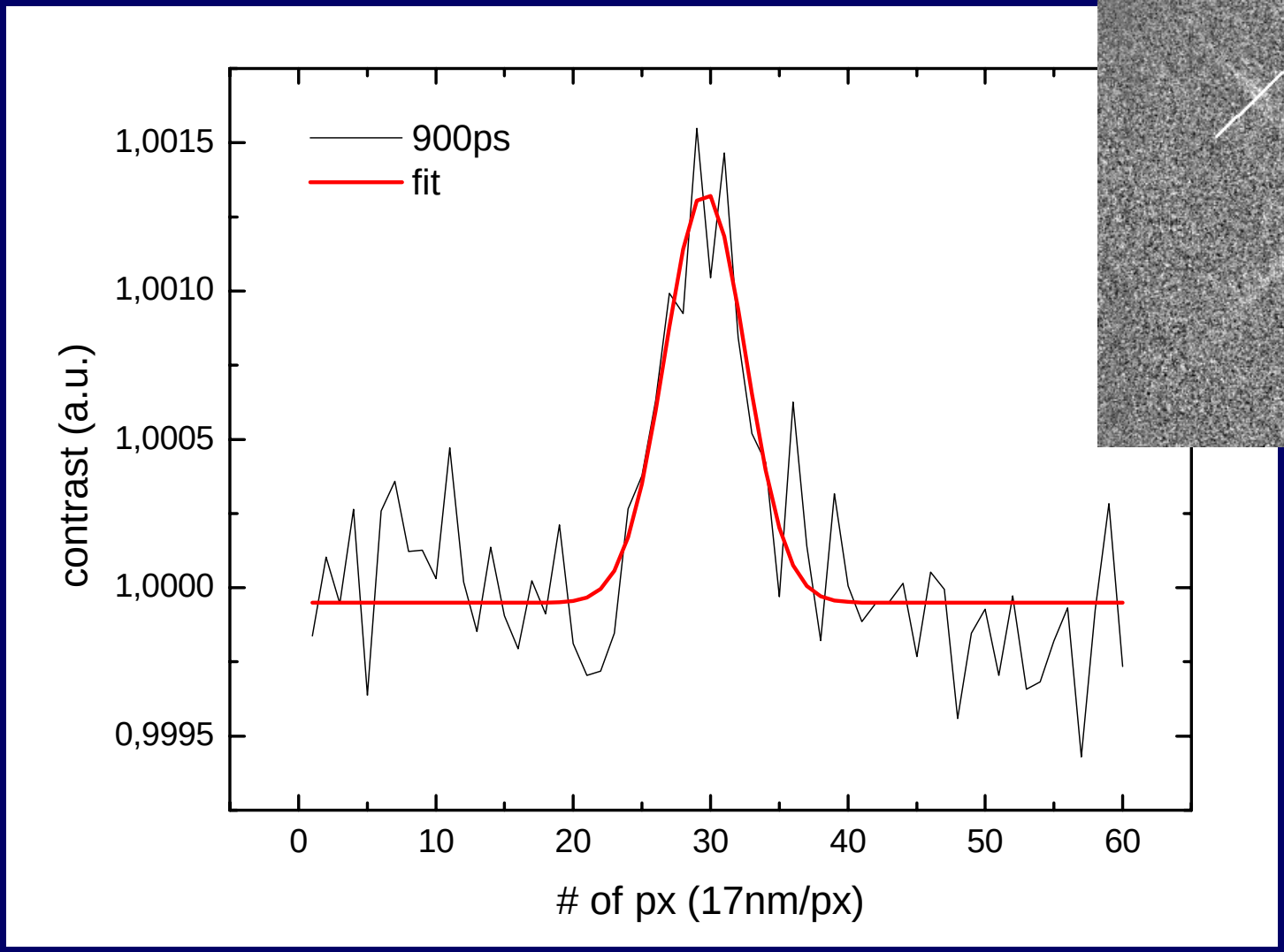
Comparison with micromagnetic simulations (OOMMF)

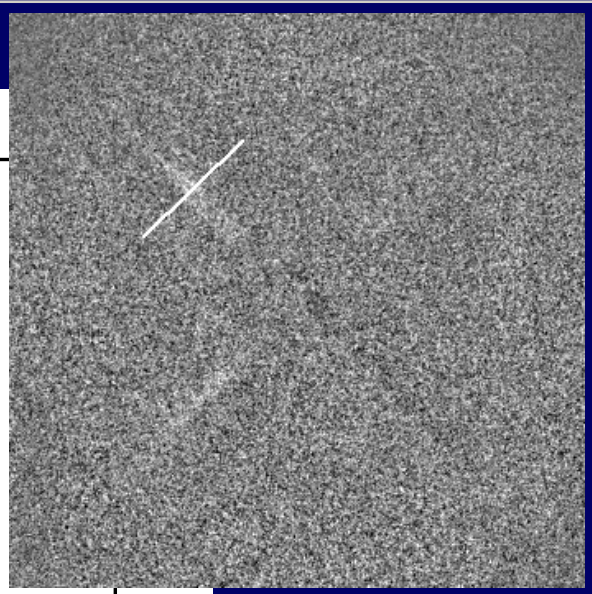
(4x4)μm^2x50nm PY

Δt=–400ps Δt=+400ps Δt=+500ps Δt=+600ps Δt=+800ps

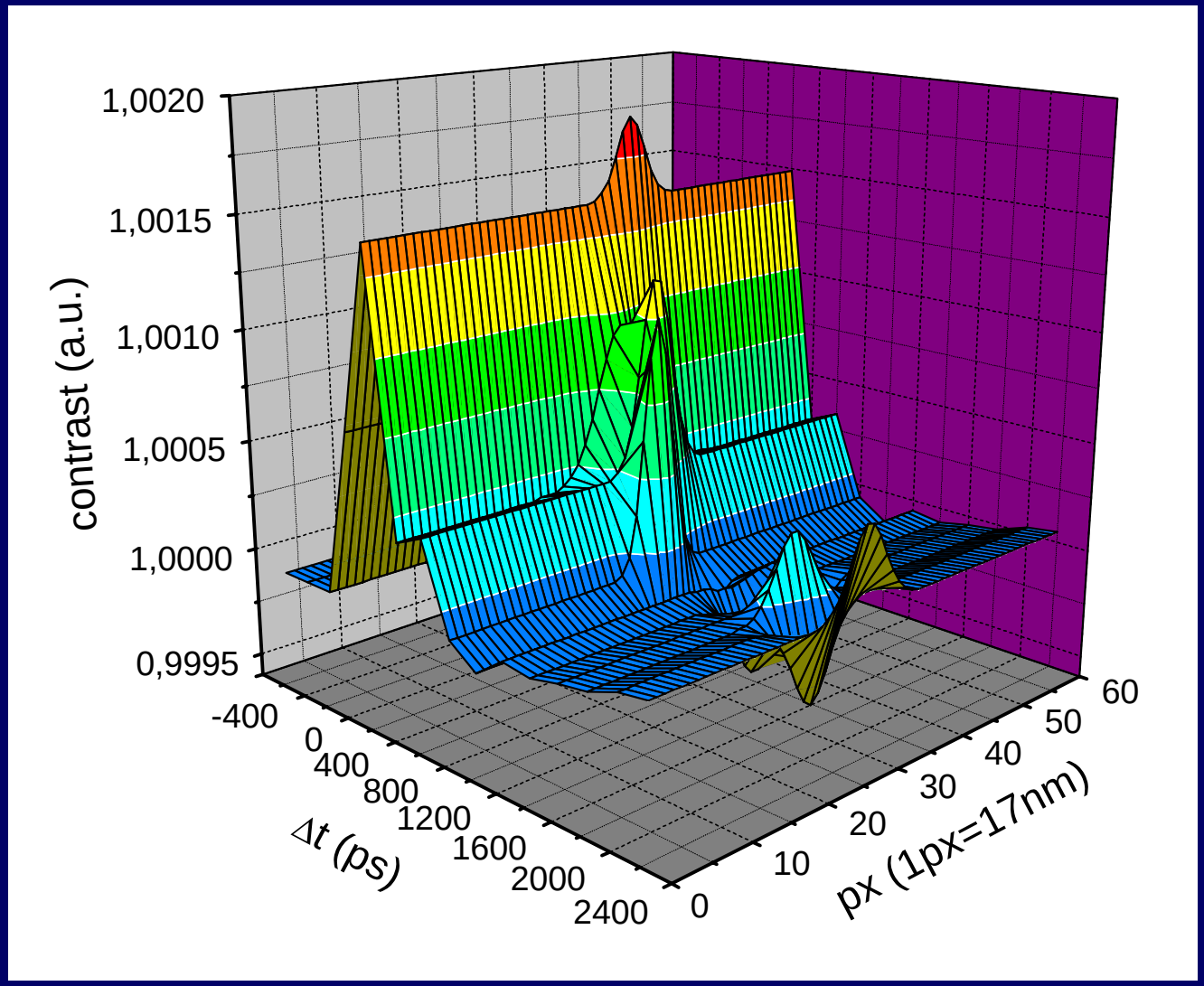


Analysing local variations



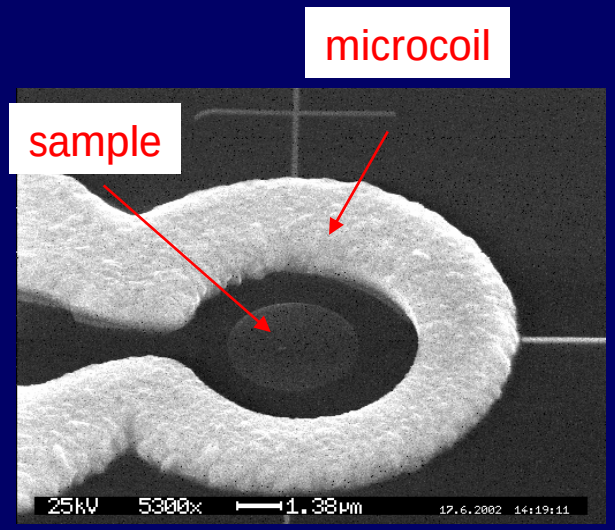


Local magnetization dynamics

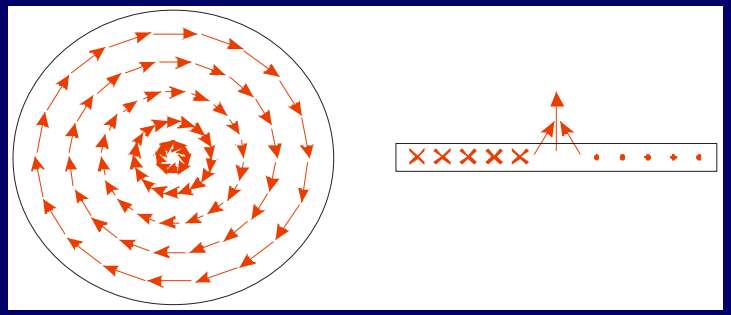


Magnetization dynamics in a circular dot

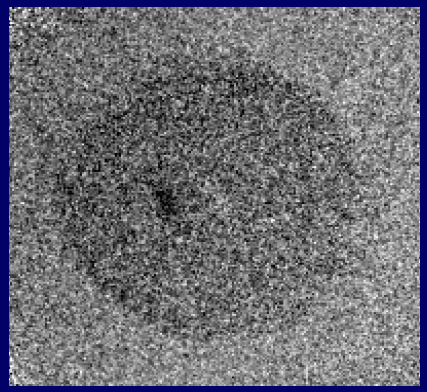
sample: 2μm diam x 50 nm PY



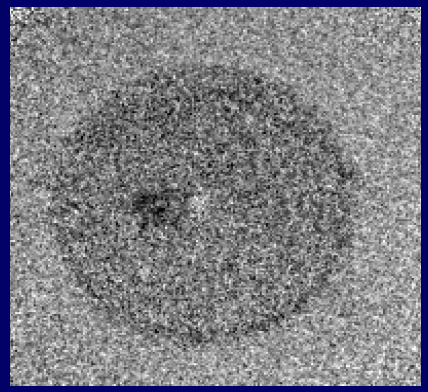
static configuration



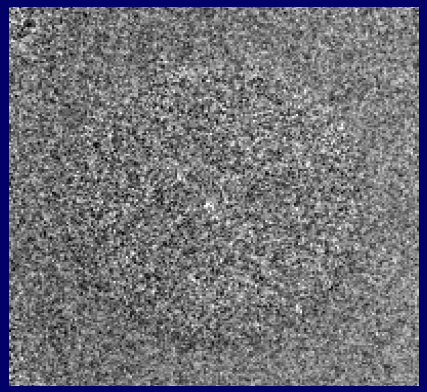
Δt=+180ps



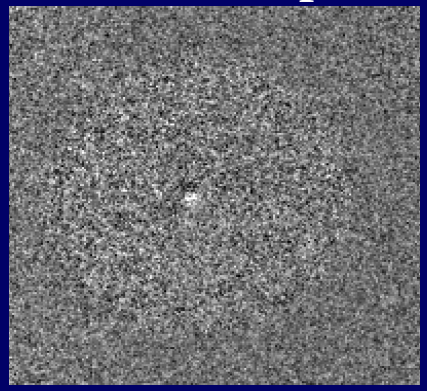
Δt=+380ps



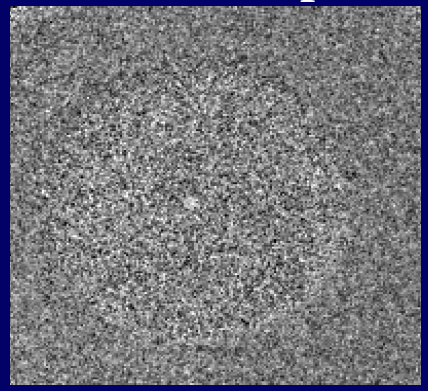
Δt=+580ps



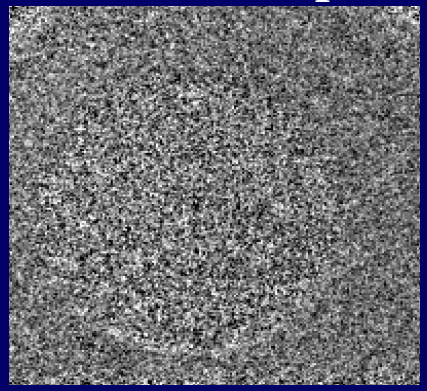
Δt=+780ps



Δt=+980ps

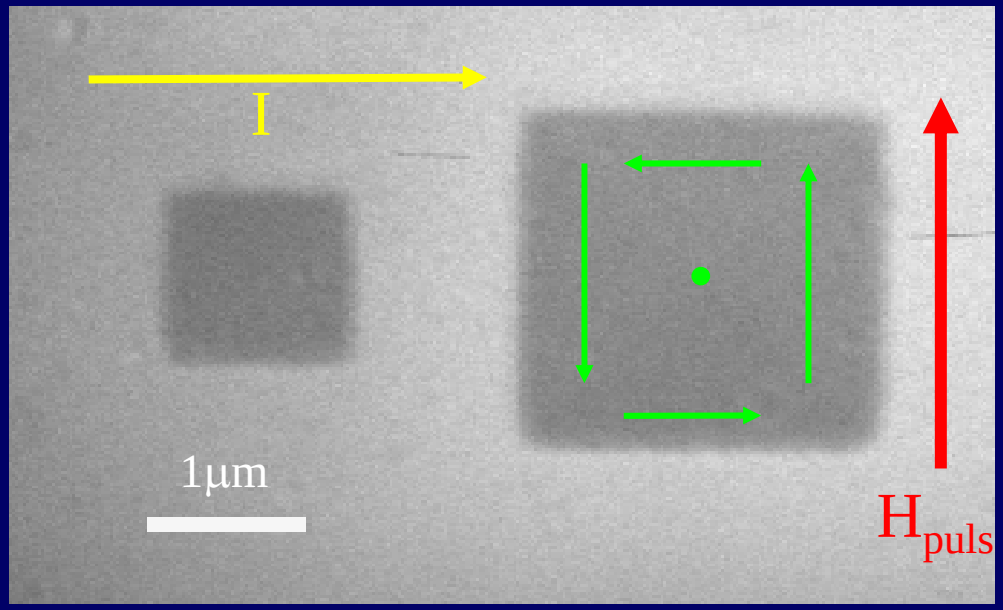


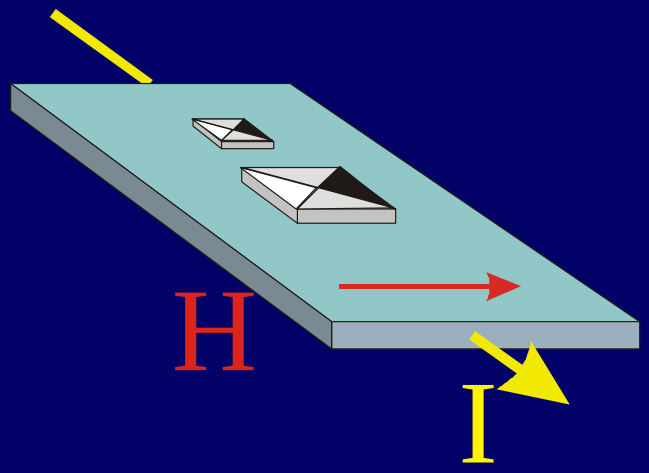
Δt=+1380ps



Pumping with striplines

sample: 50 nm PY

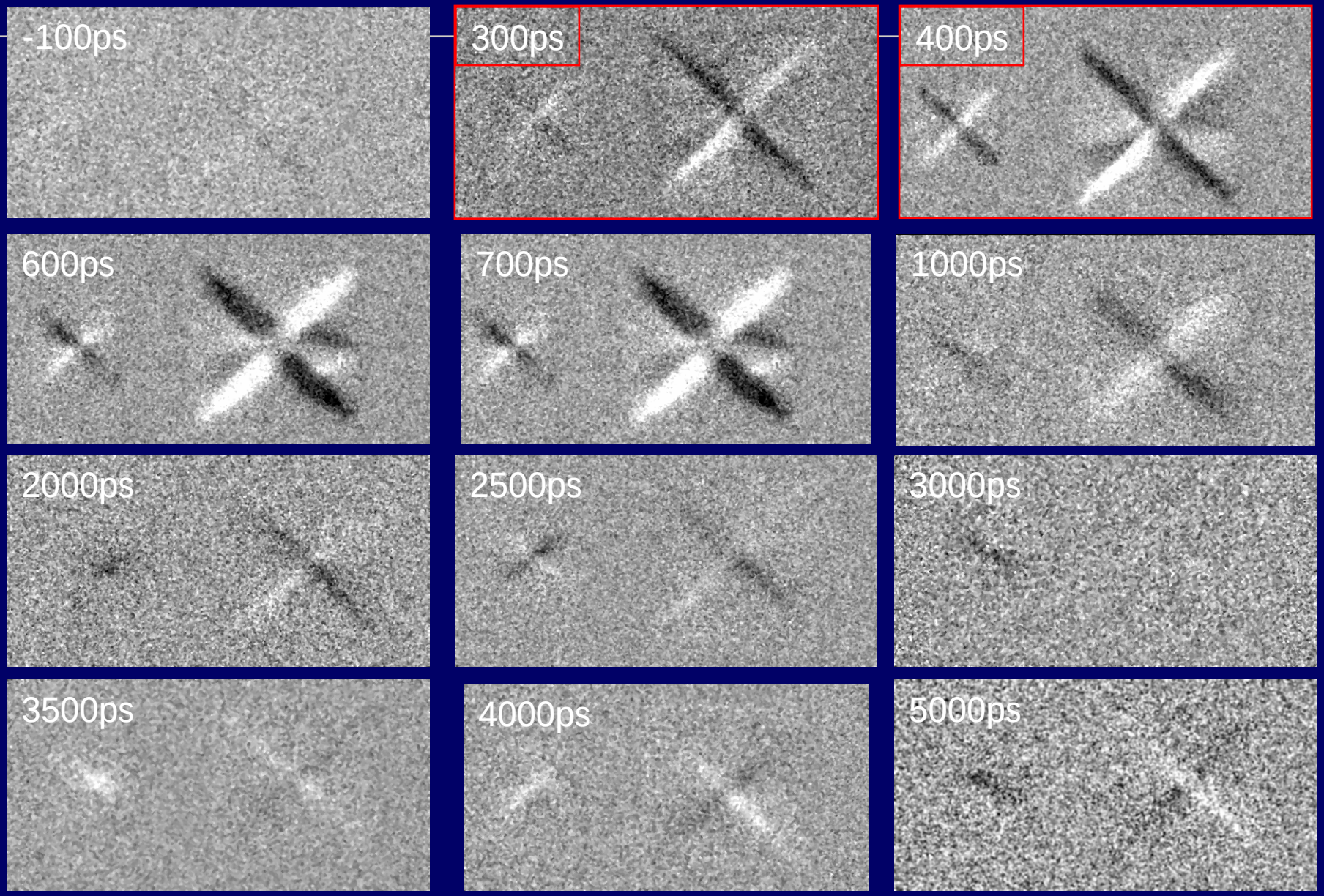




- initial field pulse in the plane of the sample

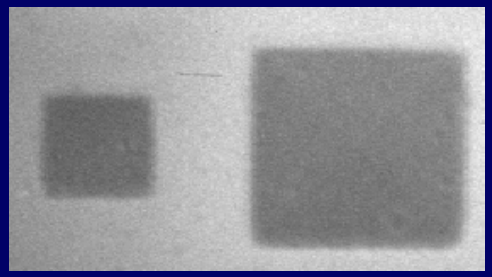
sample by K. Rott (U Bielefeld)

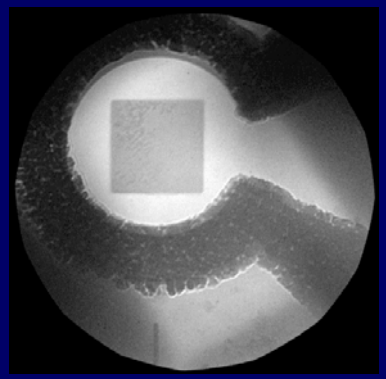
Vortex dynamics

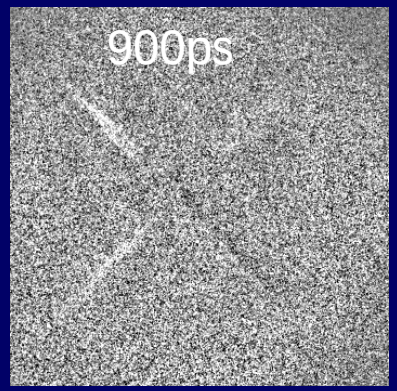


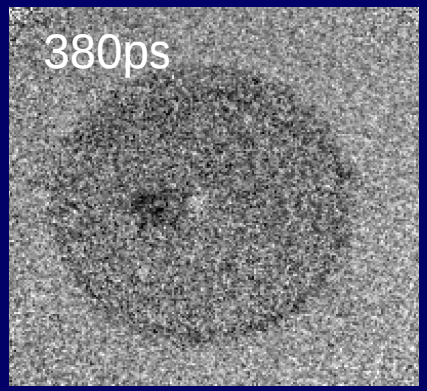
Magnetic transmission X-ray microscopy

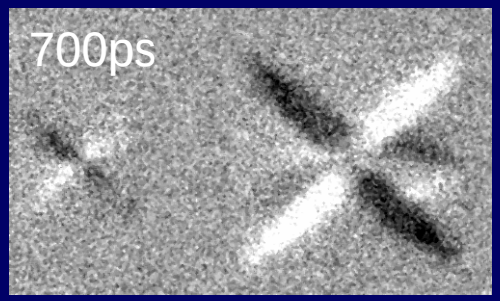
- lateral resolution at 25nm
- time resolution in the sub-ns regime
- element specific imaging











⇒ lateral and temporal evolution of magnetization

Outlook

- improving the lateral resolution $\rightarrow$ approaching >10nm
- domain wall motion in confined systems
- reversal in magnetic recording

- M-STXM $\rightarrow$ scanning vs full-field
- spin dynamics $\rightarrow$ lock-in techniques
- soft X-ray microscopy $\rightarrow$ fs spin dynamics ?!