Pulse-triggered detection of resonant magnetic small-angle scattering (mSAXS) at a laser-driven X-ray source with sub-10 ps temporal resolution

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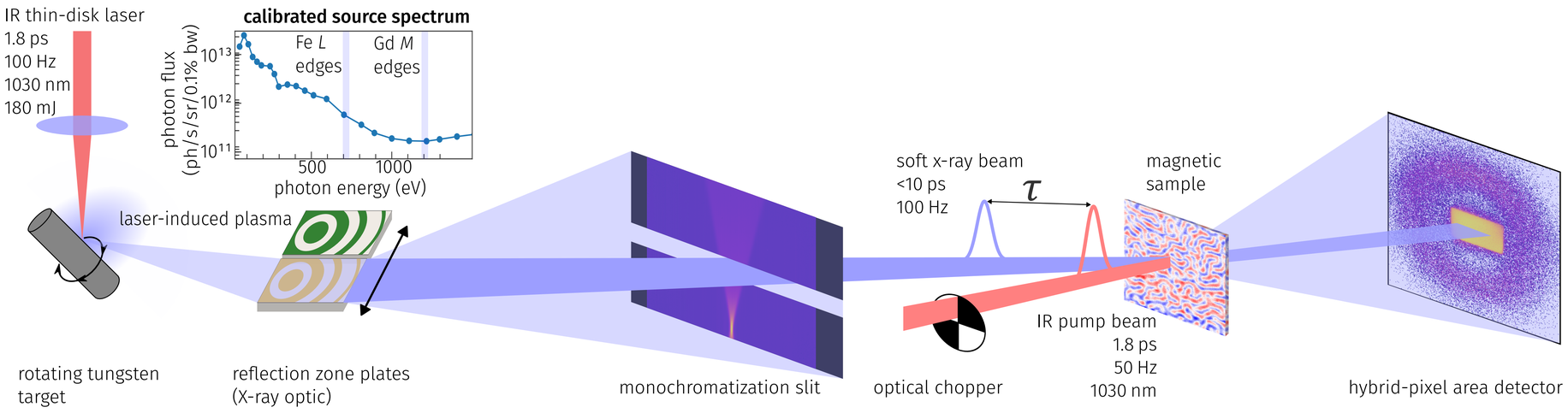
Motivation

Time-resolved resonant magnetic small-angle-X-ray (trSAXS) is a powerful tool for studying magnetization dynamics on the relevant time- and length scales [1, 2].

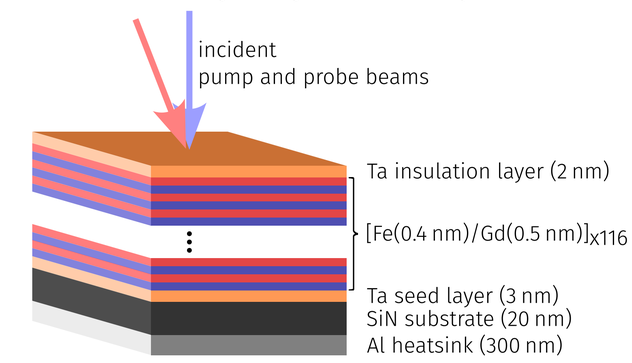
For the *L* and *M* edges (500-1500 eV) of transition and rare-earth metals, respectively, trSAXS has been limited to large-scale facilities such as synchrotrons or free-electron lasers.

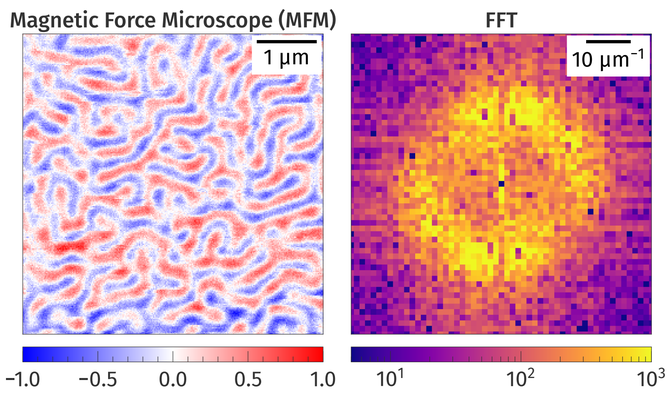
Here we present the first results of trSAXS measured at a tabletop soft x-ray plasma lab source at the Fe L_3 (707 eV) and Gd M_5 edges (1189 eV), with sub-10 ps temporal resolution on magnetic domains of a Fe/Gd mulilayer sample.

Schematic setup of the SXR laser-driven plasma source [3]



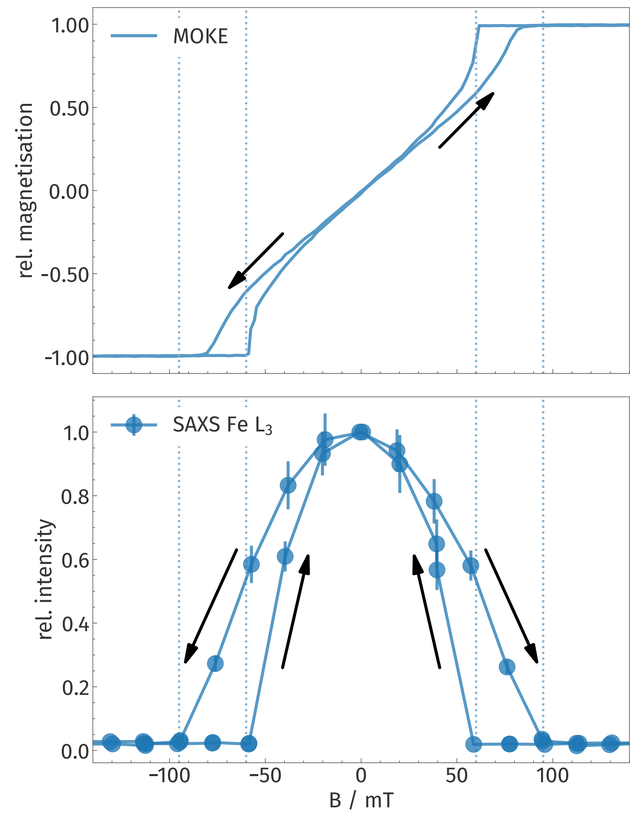
Fe/Gd multilayer system sample [4]





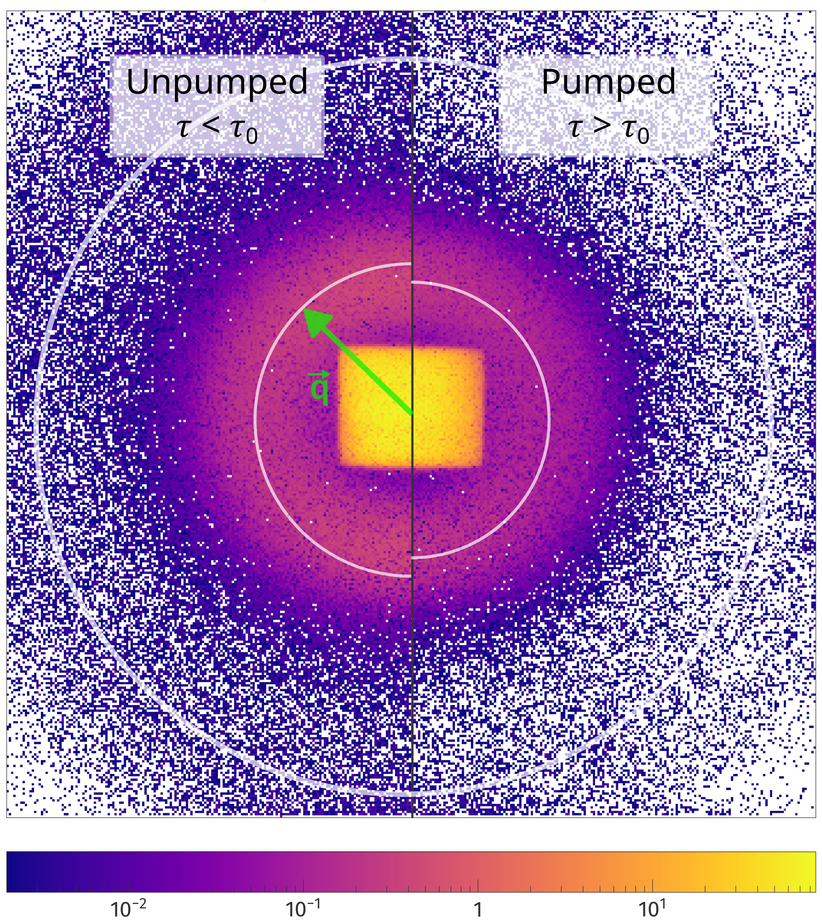
- multilayer sample system of 0.4 nm Fe and 0.5 nm Gd
- grown on SiN membrane of size 0.5 mm x 0.5 mm
- 3 nm of Ta was introduced as seed and insulation layer
- 300 nm of Al were applied as heatsink from the back

Hysteresis scans



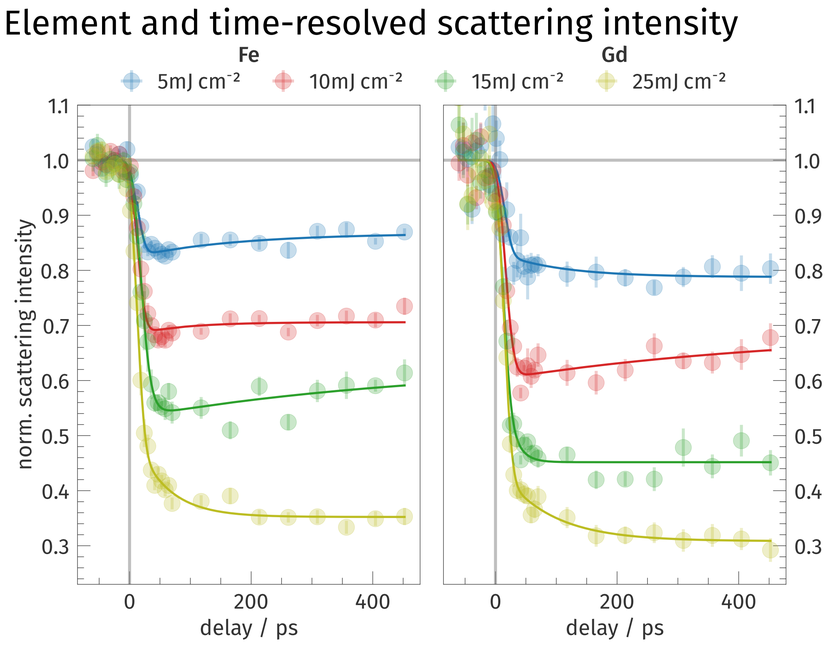
- optical MOKE probes the average ferromagnetic order not resolving magnetic domains
- without external field: sample exhibits domain pattern
- intermediate field: partial domain formation
- at saturation: all spins are aligned parallel (FM) to OOP magnetic field

mSAXS scattering pattern



- SAXS pattern of the Fe/Gd multilayer
- left half: unexcited state; right half: averaged photoexited states for delays τ between 50 ps to 700 ps
- intensity of the scattering ring $\propto M^2$
- radius of the scattering ring correlates with scattering vector $\vec{q} \propto$ average correlation length of magnetic domains
- no beam block required

Element and time-resolved scattering intensity



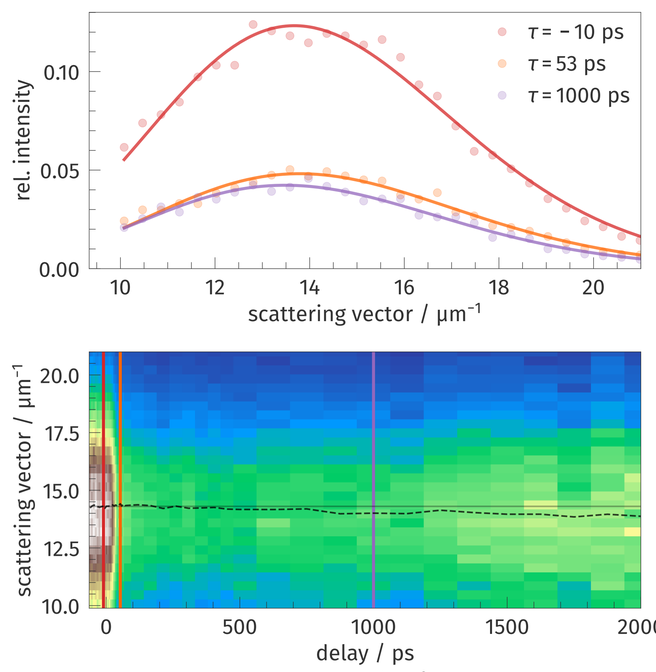
- comparison of fluence dependency of demagnetization for Fe vs Gd
- at delay τ = 0 ps sample is photoexited by 1.8 ps (FWHM) IR pulse
- scattering intensity drops rapidly due to demagnetization
- up to 70% demagnetization with increasing fluence

Conclusion & Outlook

The presented setup enables systematic studies of complex magnetic phenomena on a laboratory scale. Our results demonstrate element- and time-resolved access to picosecond time and nanometer length scales of the observed dynamics. Additional environmental control by temperature and magnetic fields allow exploring the rich phase diagram of magnetic nanostructures in more detail.

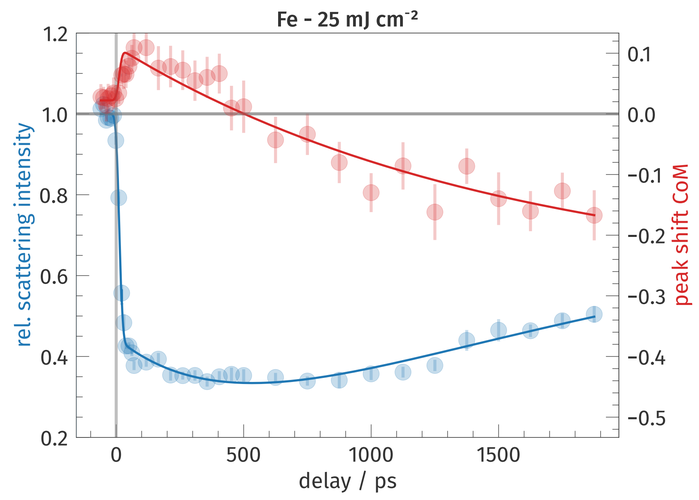
Time-resolved 1D azimuthal integrated intensities

- azimuthally integrated and q-transformed mSAXS intensity
- time-resolved scattering intensity at selected delays
- well-described and fitted with Gamma function



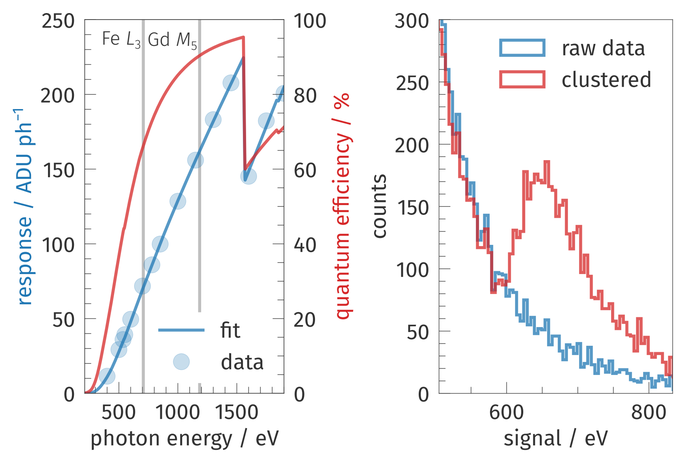
- full set of trSAXS data at 25 mJ/cm² Fe L_3 edge
- shift of peak position (domain correlation length/size)

Scattering intensity and peak shift



- demagnetization and peak shift for Fe at fluence of 25 mJ cm^{-2}
- different time scales indicate dynamics of different processes

MOENCH detector [5]



- unique combination of technical features:
  - 400 px x 400 px resolution
  - 25 µm pixel size
  - up to 1.5 kHz acquisition rate
  - <50 ns trigger jitter
  - 33 e- noise RMS at 100 ns exposure
- the low noise level and high quantum efficiency enables application of single-photon-counting algorithms in the soft X-ray regime

References

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[3] D. Schick et al., Optica 8, 1237-1242 (2021)
[4] A. Tripathi et al., PNAS 108(33), 13393-13398 (2011)
[5] M. Ramilli et al., JINST 12, C01071 (2017)