Ultrafast holographic imaging of nanosized magnetic systems during optical demagnetization.

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Motivation

Heating of a ferromagnet close to its specific Curie temperature T_C will destroy the long range ordering represented by the individual microscopic magnetic moments. Here, typical electron thermalization processes take place down to the picosecond time scale. Beside heating, one can observe a much faster demagnetization process by using ultra-short optical laser pulses impinging onto thin magnetic films [1].

Thin multilayer systems which exhibit a perpendicular magnetic anisotropy [2] and are laterally structured, e.g. showing a disordered domain structure, are of special interest for spintronic applications. Recently, it has been shown in an optical pump—XUV probe scattering experiment at FLASH [3] that for this kind of systems an **ultrafast demagnetization on a femtosecond time scale** can be measured at FEL sources (Fig. 1). Furthermore, an unexpected **ultrafast spatial response** in the same time domain occurs (Fig. 2). Monte-Carlo simulations revealed that this effect can be explained by a **superdiffusive transport of spin-polarized electrons** across the domain walls [4].

To further deepen the understanding of the underlying processes during optical demagnetization and to prove the validity of the applied models we performed a **time-resolved optical pump — XUV probe imaging experiment** at the free-electron laser facility FERMI@Elettra [5,6]. We used soft x-ray **Fourier transform holography (FTH)** [7,8] as imaging technique and exploit the XMCD effect as magnetic contrast mechanism. For the first time we were able recover the real-space domain structure during ultrafast optical demagnetization.

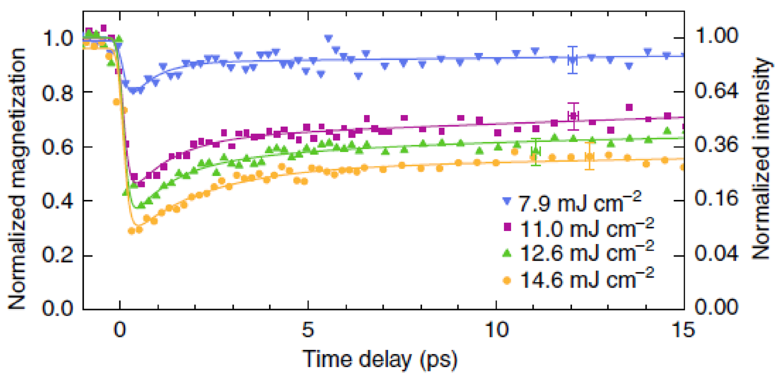


Figure 1: Ultrafast optical demagnetization.

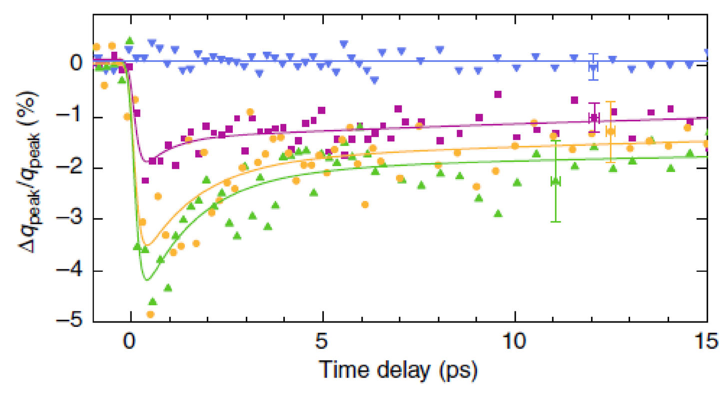


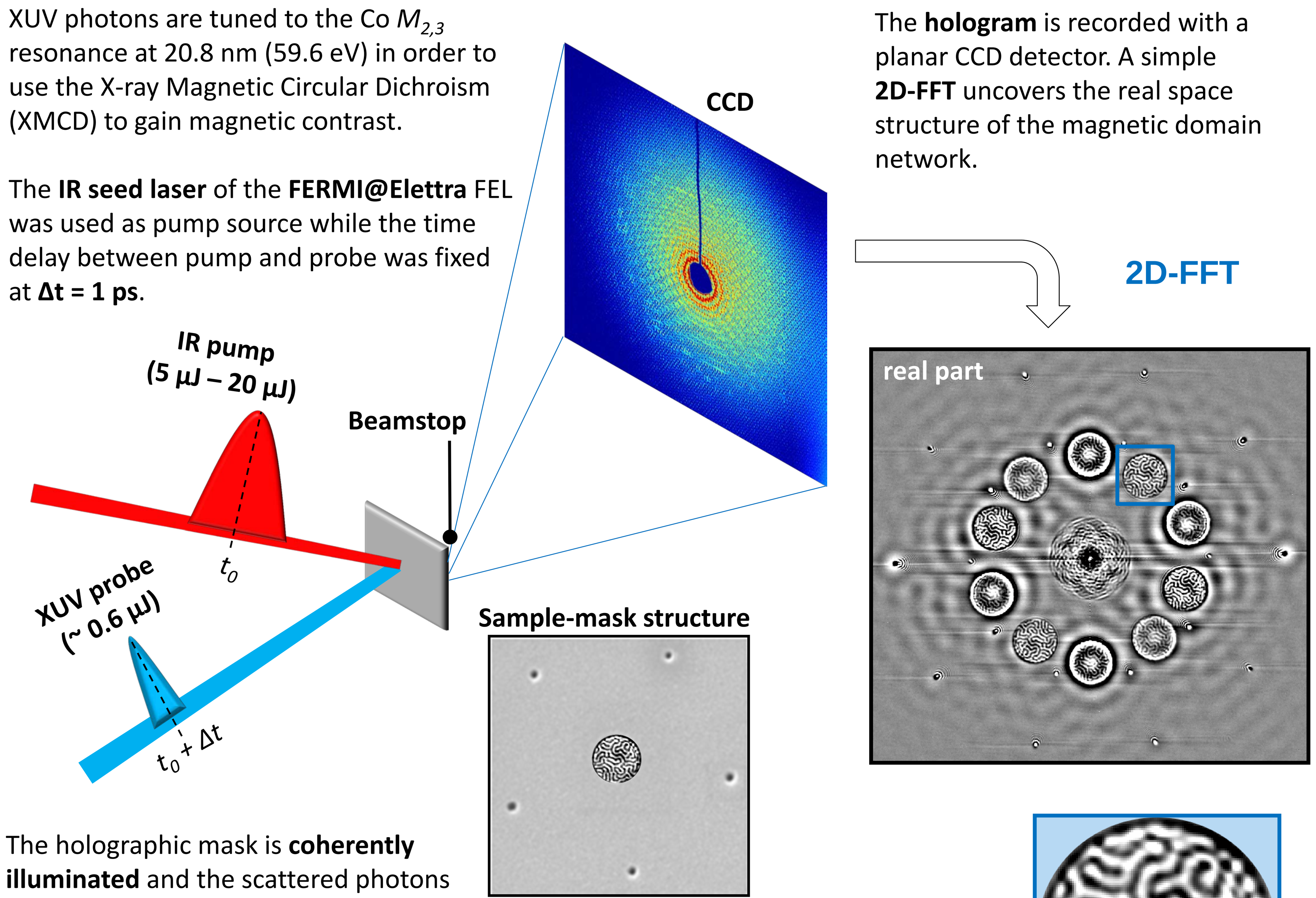
Figure 2: Ultrafast spatial response.

Time-resolved soft X-ray Fourier transform holography (FTH)

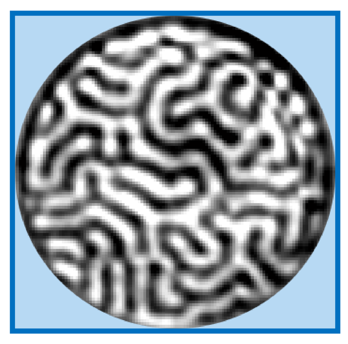
The **circularly polarized and coherent** XUV photons are tuned to the Co $M_{2,3}$ resonance at 20.8 nm (59.6 eV) in order to use the X-ray Magnetic Circular Dichroism (XMCD) to gain magnetic contrast.

The **IR seed laser** of the **FERMI@Elettra** FEL was used as pump source while the time delay between pump and probe was fixed at **Δt = 1 ps**.

The **hologram** is recorded with a planar CCD detector. A simple **2D-FFT** uncovers the real space structure of the magnetic domain network.



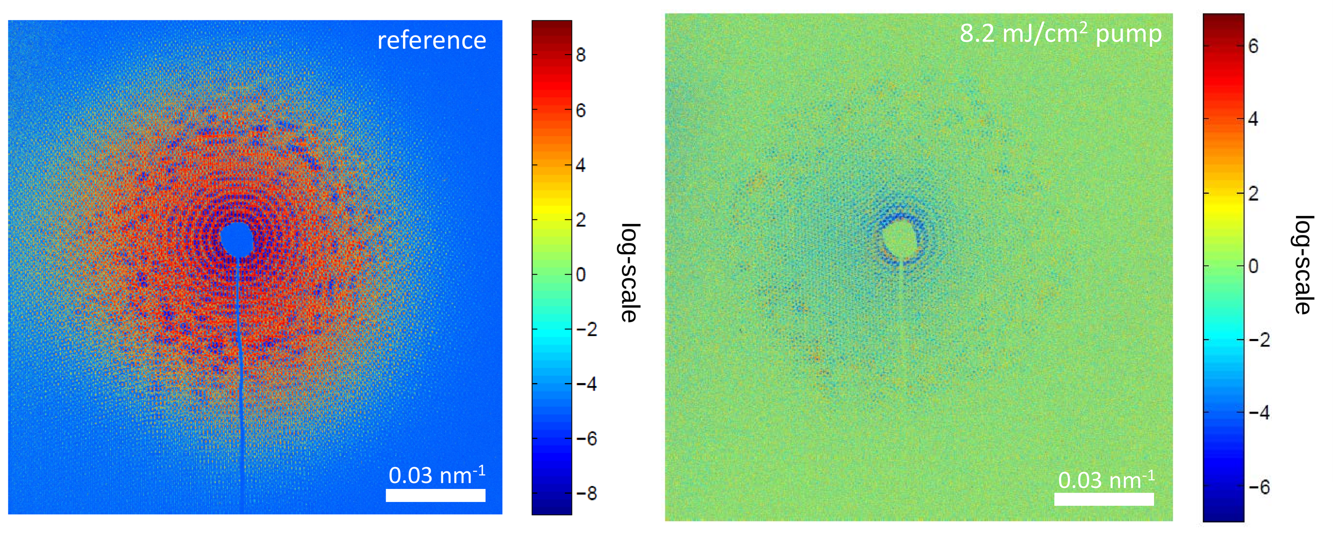
The holographic mask is **coherently illuminated** and the scattered photons from the object hole, which are carrying the magnetic information, are interfering with the scattered photons from the reference holes. Thus, the **phase information** is encoded in the far-field hologram.



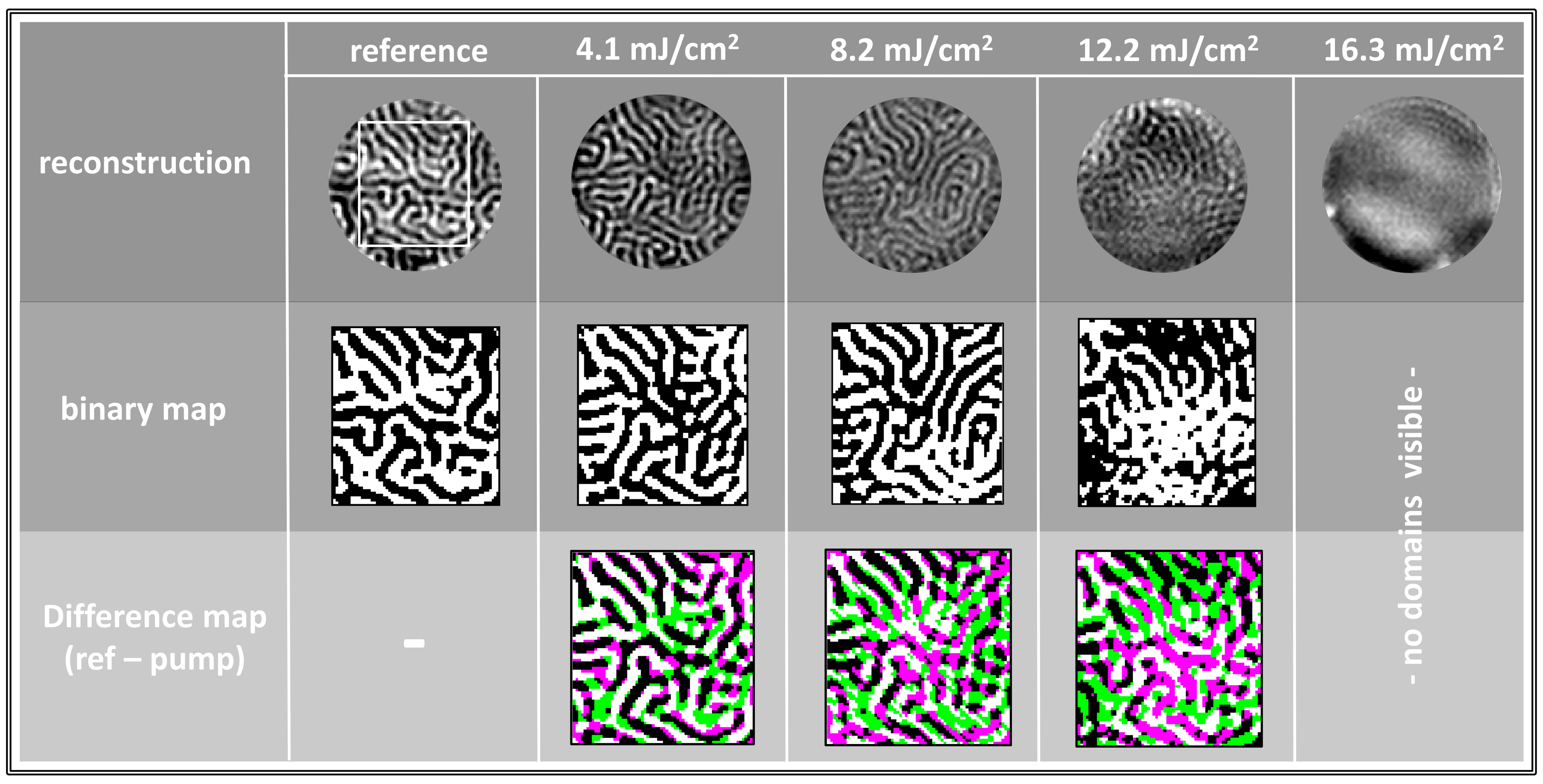
The **80 nm** wide black/white areas are representing the magnetic moments, pointing perpendicular to the sample surface.

Results and Discussion

- Multishot experiment (~6000 pulses/hologram).
- Measure holograms with circular left and right polarized photons and calculate the difference hologram to get rid of the charge scattering.
- Single-shot imaging not possible due to **XMCD quenching** at higher fluences [9]

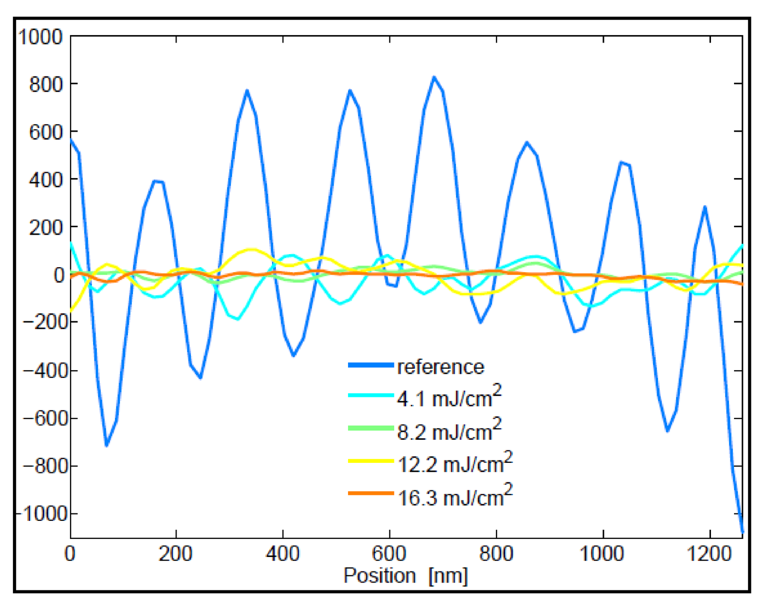


→ Ultrafast decrease of the magnetic scattering contrast

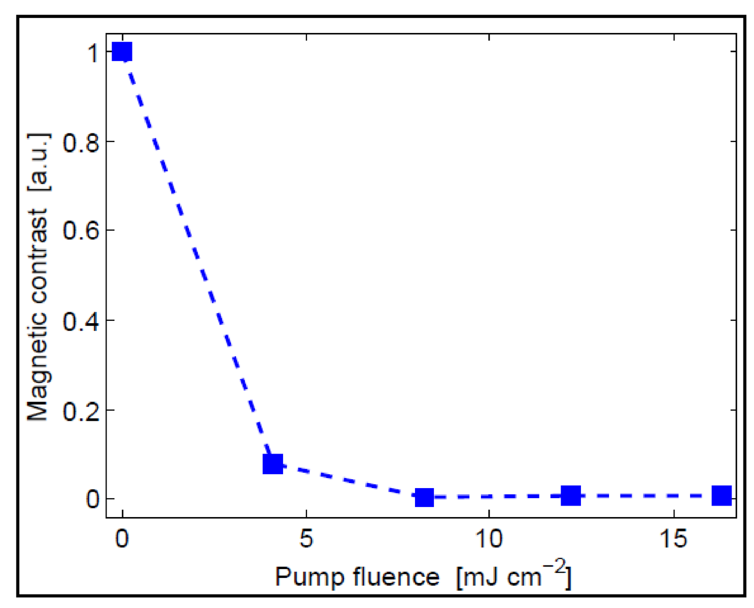


- **Domain blurring** observed due to superdiffusive spin-transport.
- Demagnetization starts from the bottom side of the reconstruction
  → demagnetization gradient due to inhomogeneous IR pump exposure (see reconstruction at 12.2 mJ/cm² pump fluence).
- Magnetic domains vanish completely at 16.3 mJ/cm² pump fluence.

Linescans through reconstructions



Magnetization vs. pump fluence



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