

# Probing ultrafast magnetization dynamics with soft X-rays

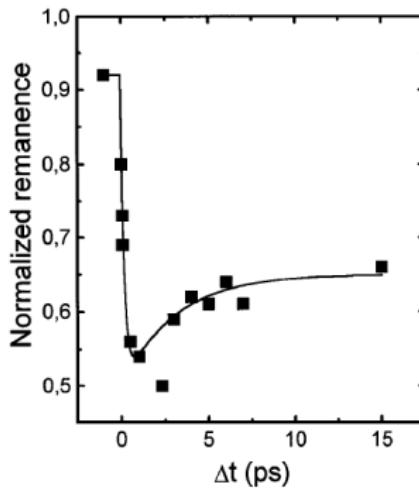
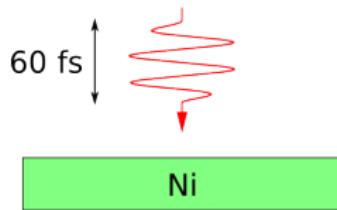
B. Vodungbo, A. Merhe, X. Liu, E. Jal., J. Lüning

Laboratoire de Chimie Physique – Matière et Rayonnement  
Université Pierre et Marie Curie – CNRS  
Paris, France

# Overview

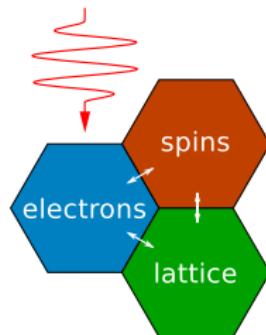
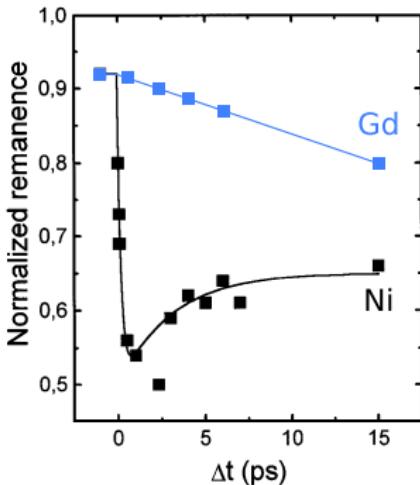
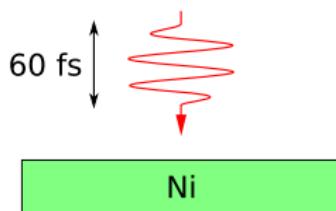
- 1 Ultrafast magnetization dynamics: context
- 2 Principles of our experiments
- 3 Higher scattering orders
- 4 Other type of experiments

# Motivation: ultrafast magnetization manipulation



Beaurepaire et al., Phys. Rev. Lett. 76, 4250 (1996)

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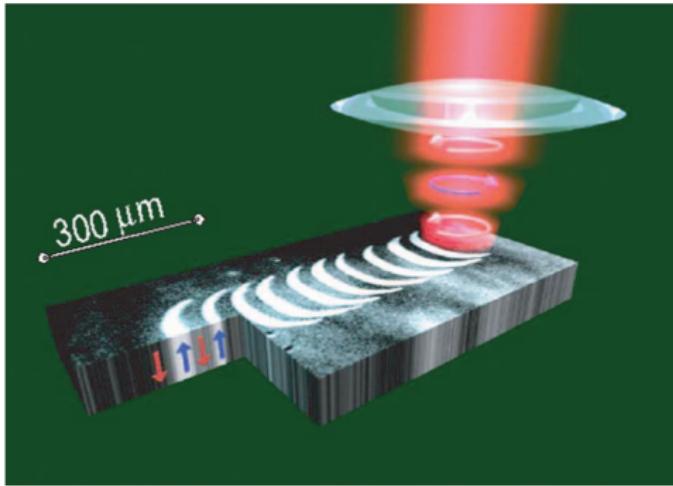


- contradiction with expectations and previous observations
- no satisfactory physical explanation (angular momentum transfer?)

Beaurepaire et al., Phys. Rev. Lett. 76, 4250 (1996)

Vaterlaus et al., Phys. Rev. Lett. 67, 3314 (1991), Kirilyuk et al., Rev. Mod. Phys 82, 2731 (2010)

# Motivation: ultrafast magnetization manipulation



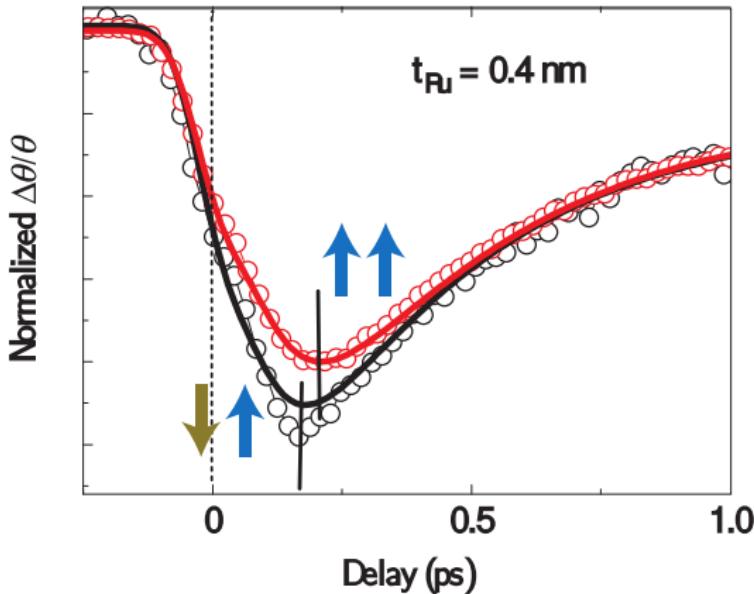
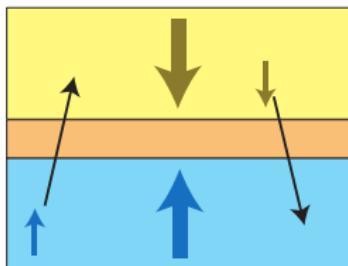
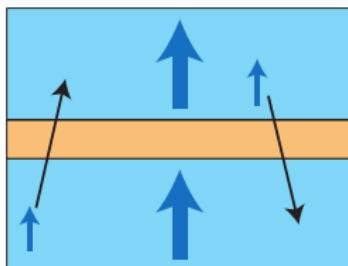
- contradiction with expectations and previous observations
- no satisfactory physical explanation (angular momentum transfer?)
- application to femtosecond control of magnetization

Beaurepaire et al., *Phys. Rev. Lett.* 76, 4250 (1996)

Vaterlaus et al., *Phys. Rev. Lett.* 67, 3314 (1991), Kirilyuk et al., *Rev. Mod. Phys.* 82, 2731 (2010)

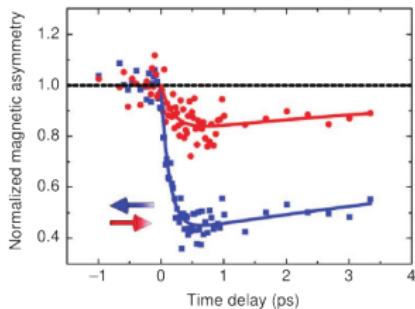
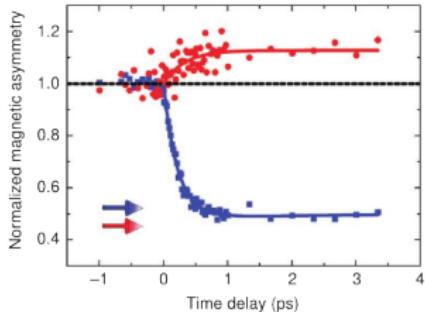
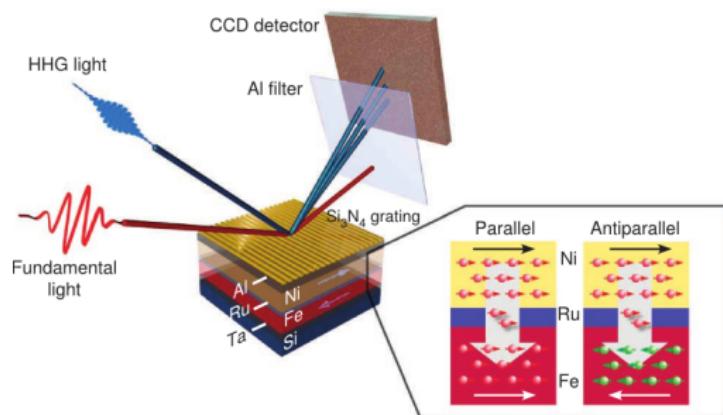
Stanciu et al., *Phys. Rev. Lett.* 98, 207401 (2007)

# Superdiffusive spin transport: experimental reports



Malinowski et al., *Nature Phys.* 4, 855, (2008)

# Superdiffusive spin transport: experimental reports



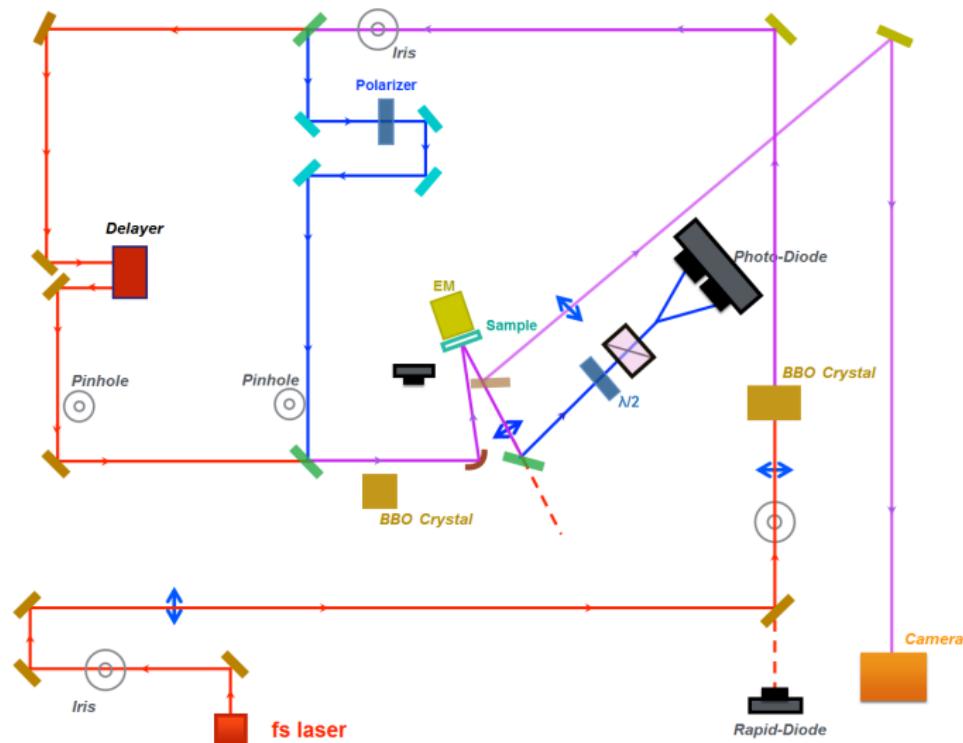
Rudolf et al., Nat. Commun. 3, 1037 (2012)

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- 1 Ultrafast magnetization dynamics: context
- 2 Principles of our experiments
- 3 Higher scattering orders
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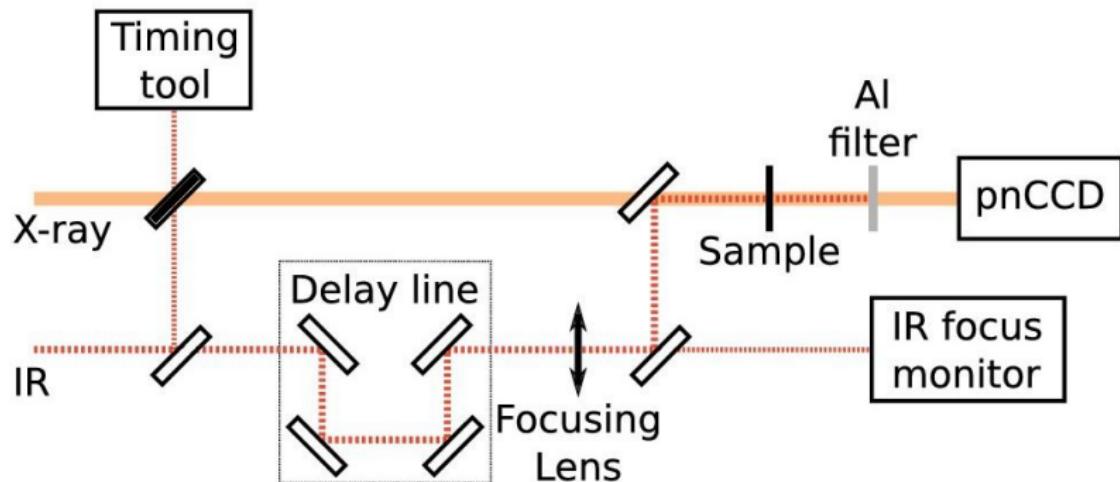
# Typical pump/probe setup

Time-resolved MOKE: IR pump/visible probe



# Typical pump/probe setup

IR pump/X-ray probe

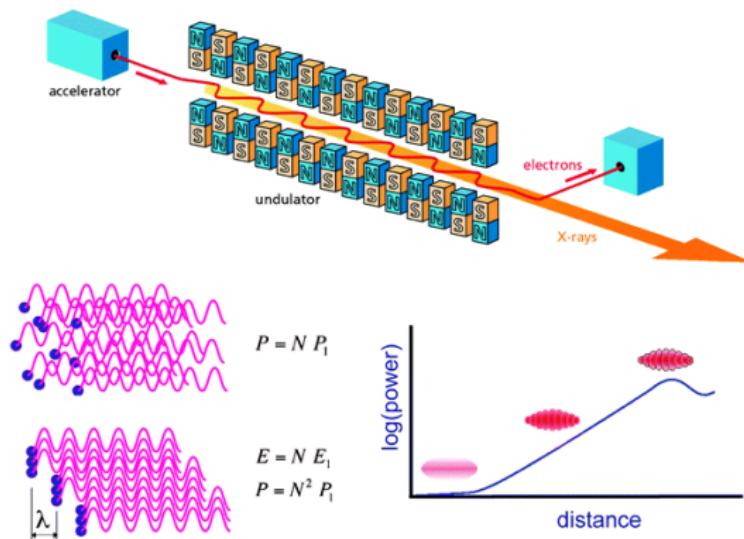


Advantages of X-rays:

- short pulses ( $< 1$  fs): better time resolution
- short wavelength ( $< 1$  nm): better spatial resolution
- absorption spectroscopy: element specificity

# Femtosecond EUV and X-ray sources

X-ray Free Electron Laser, XFEL (only a few operated worldwide)

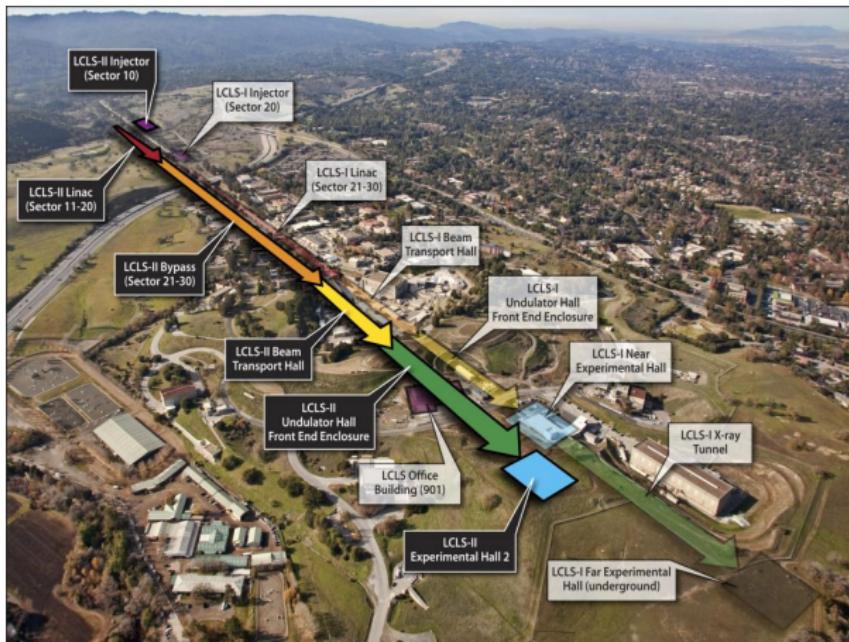


- Photon energy up to 13 keV, pulse duration down to 2 fs
- Very bright

B.D. Patterson et al., Phys. Chem. Chem. Phys., 12, 5647 (2010)

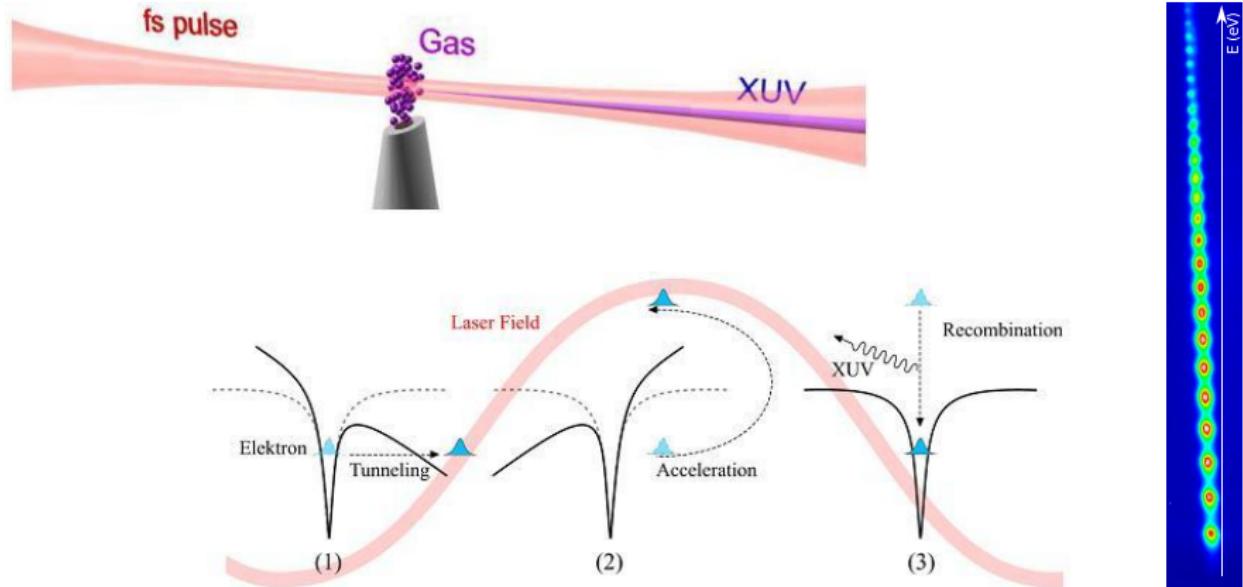
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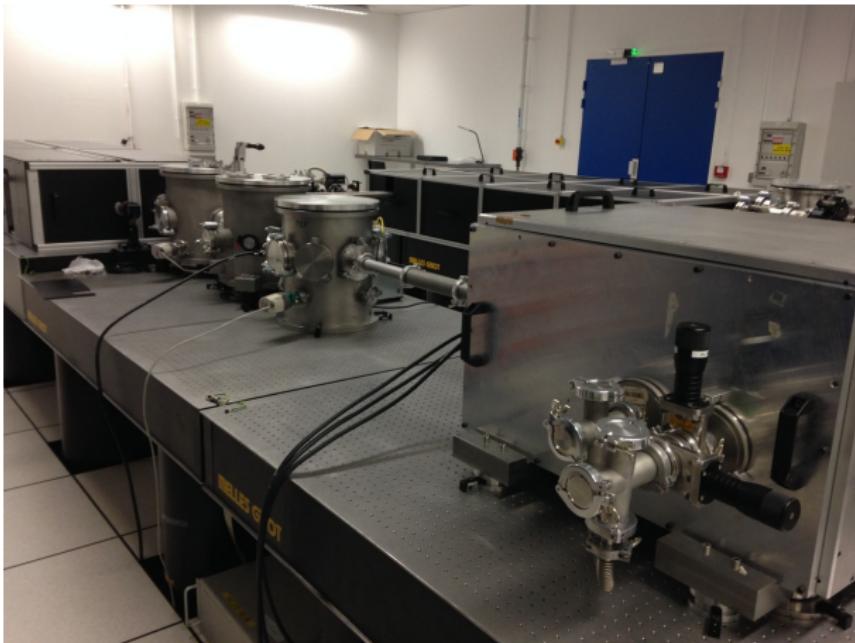
# Femtosecond EUV and X-ray sources

## High Harmonics Generation in gas, HHG (table-top)



- Photon energy up to 200 eV (2 keV), pulse duration down to 100 as
- Low intensity

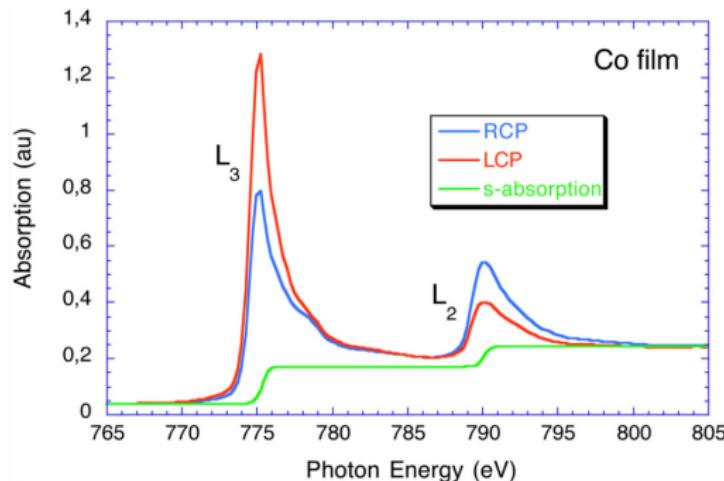
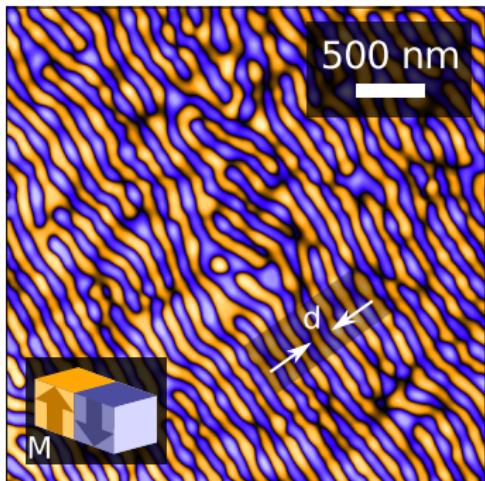
# Femtosecond EUV and X-ray sources



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- Low intensity

# Resonant magnetic scattering

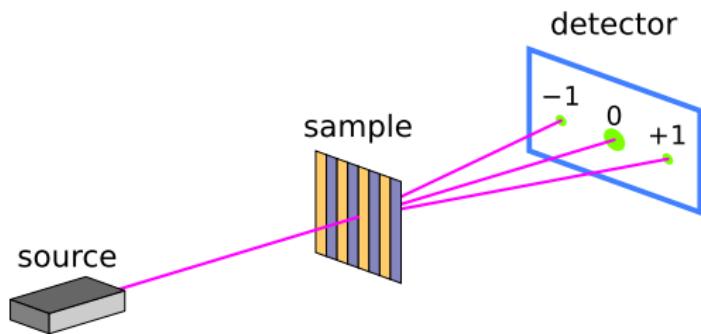
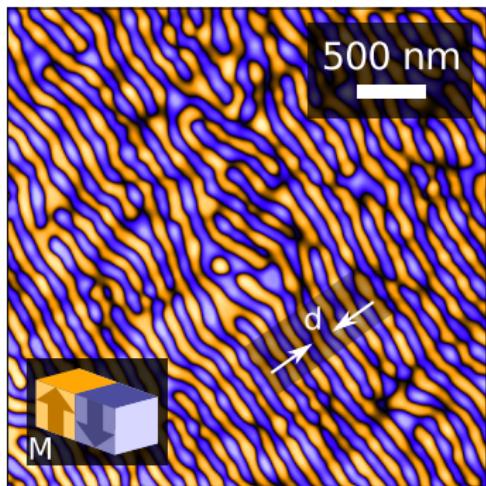
Magnetic contrast given by XMCD



Magnetic domain network = magnetic diffraction grating

# Resonant magnetic scattering

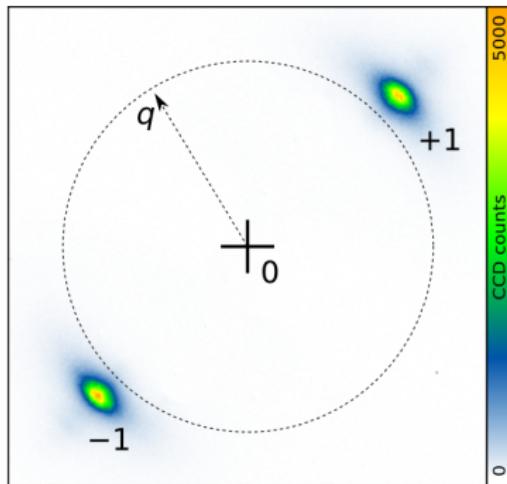
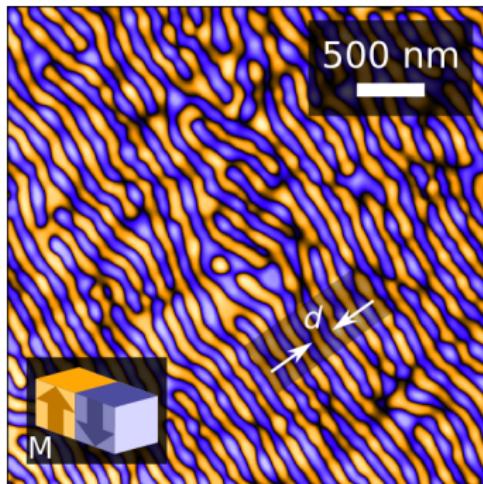
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# Resonant magnetic scattering

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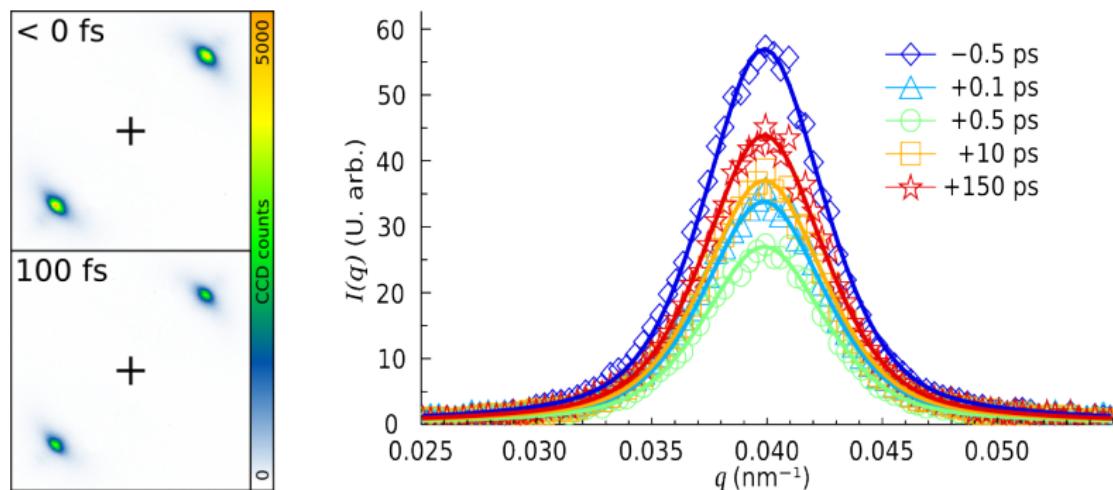
- scattering intensity  $\rightarrow$  domains magnetization ( $I \sim M^2$ )
- spots position and shape  $\rightarrow$  domains size and orientation ( $q \sim \frac{1}{d}$ )

Linear polarization ok ( $L = H^+ + H^-$ ): identical  $H+$  and  $H-$  patterns

Vodungbo et al., EPL, 94, 54003 (2011)

# Time-resolved resonant magnetic scattering

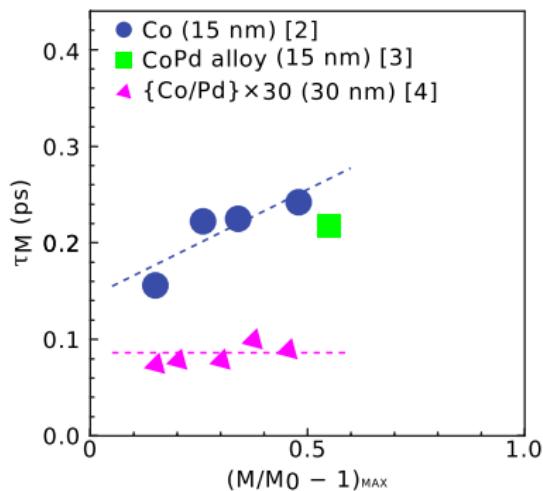
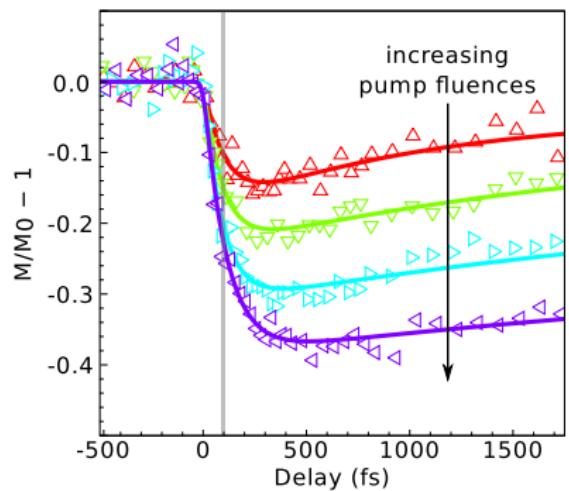
Co/Pd multilayer, HHG, LOA, France



Vodungbo et al., Nat. Commun. 3, 999 (2012)

# Time-resolved resonant magnetic scattering

Co/Pd multilayer, HHG, LOA, France



- faster demagnetization ( $\sim 100$  fs) than TR-MOKE ( $> 150$  fs)
- demagnetization time independent of the pump fluence

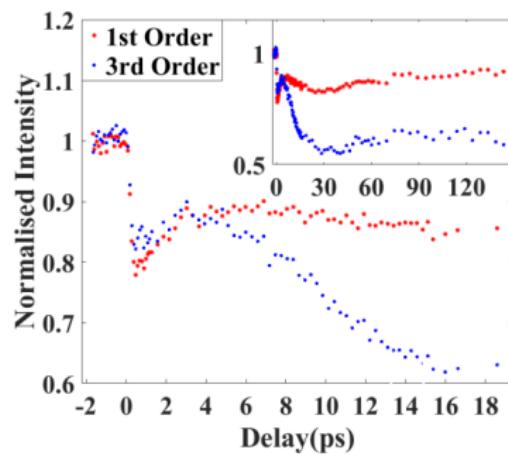
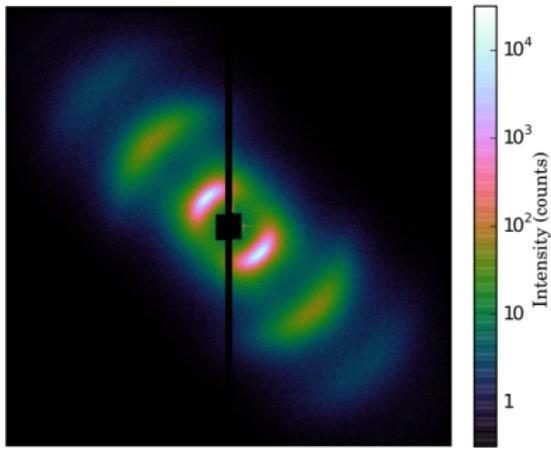
Vodungbo et al., Nat. Commun. 3, 999 (2012)

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# Magnetic anisotropy dynamic

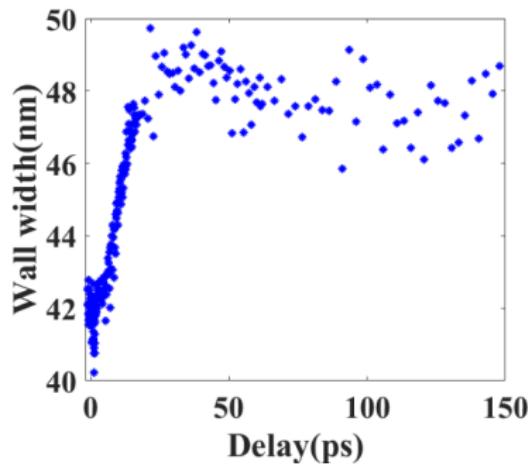
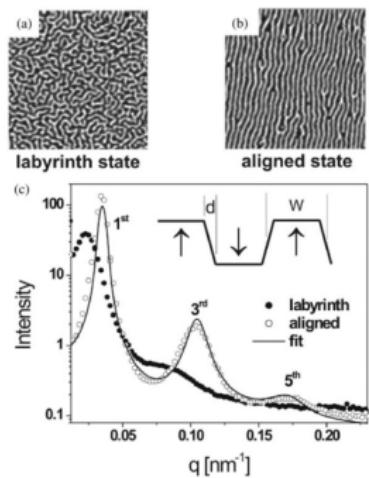
Co<sub>88</sub>Tb<sub>12</sub> (50 nm), X-FEL FERMI, 60 eV



- difference between 1st and 3rd order → structure modification

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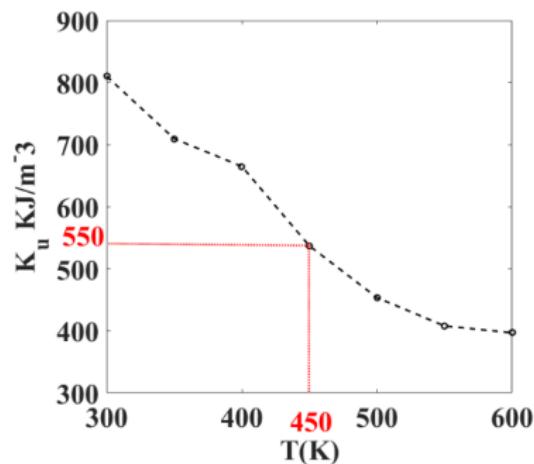
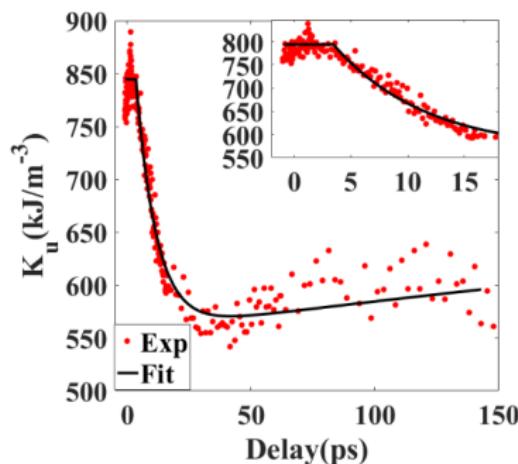


- difference between 1st and 3rd order → structure modification
- increase in domain wall size

O. Hellwig et al., Physica B 336, 136 (2003)

# Magnetic anisotropy dynamic

Co<sub>88</sub>Tb<sub>12</sub> (50 nm), X-FEL FERMI, 60 eV



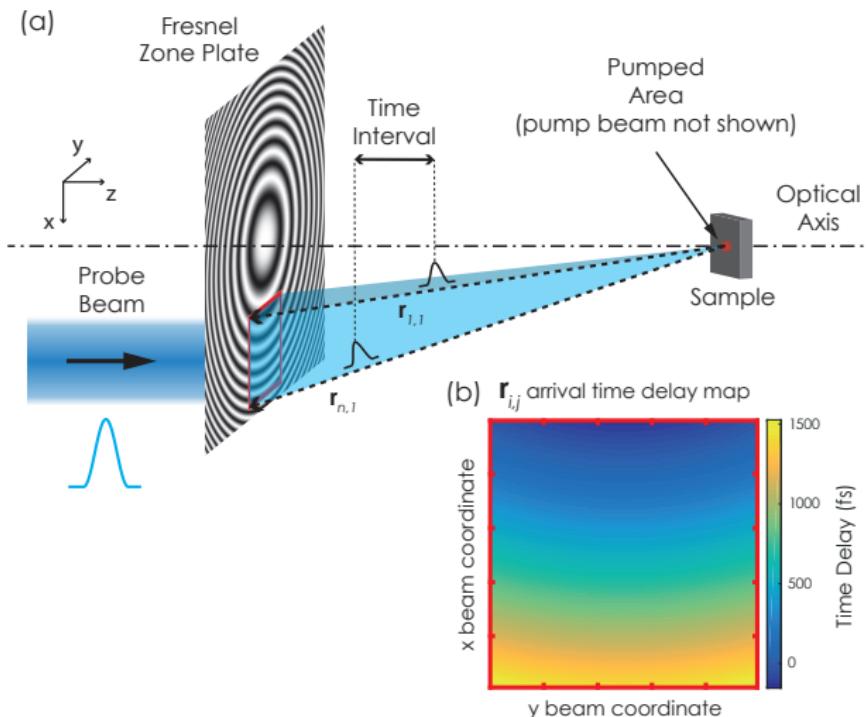
- difference between 1st and 3rd order → structure modification
- increase in domain wall size
- $d \sim \sqrt{\frac{A}{K_u}}$

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# X-ray streaking

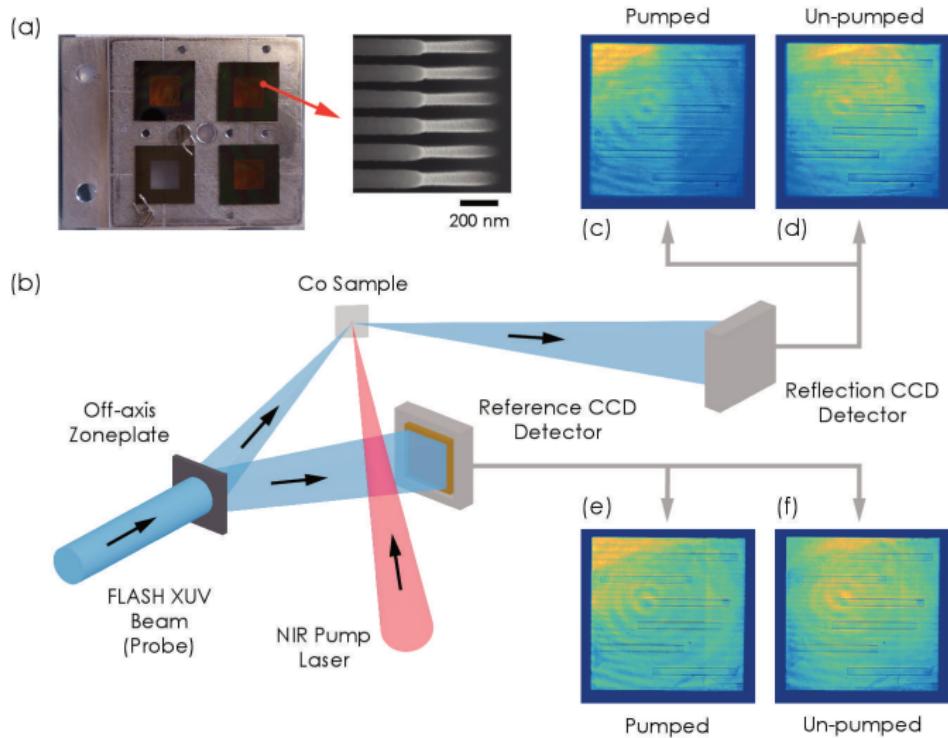
XFEL, FLASH, Germany



Buzzi et al., Scientific Report 7, 7253 (2017).

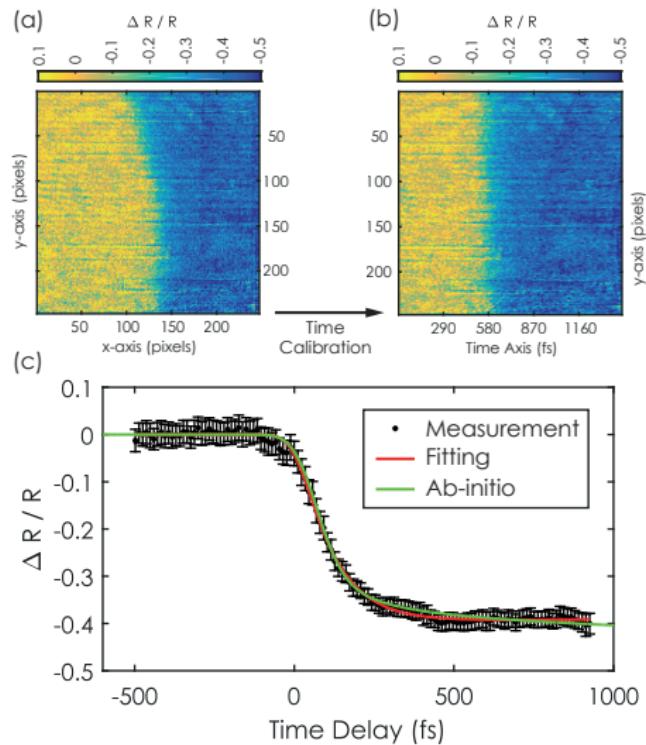
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XFEL, FLASH, Germany



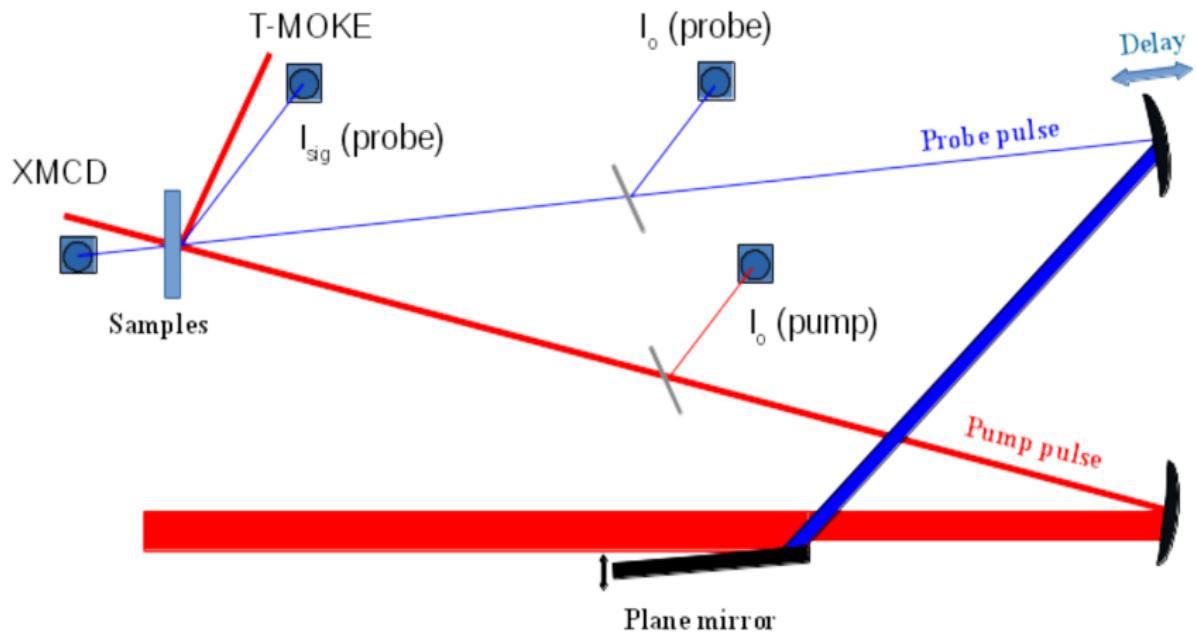
# X-ray streaking

XFEL, FLASH, Germany



# X-ray pump /X-ray probe experiment

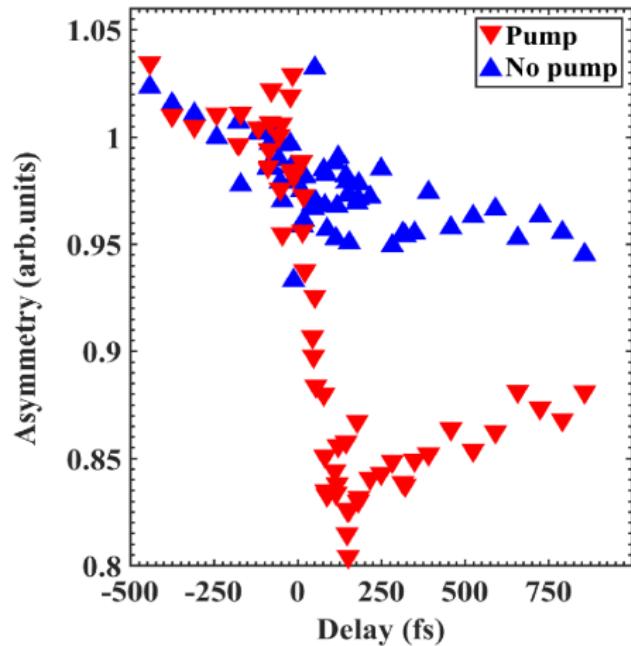
XFEL, FLASH, Germany



Using 2 fs XFEL pulses  $\Rightarrow$  sub 5 fs resolution

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XFEL, FLASH, Germany



Using 2 fs XFEL pulses  $\Rightarrow$  sub 5 fs resolution

# Acknowledgements

## Collaborations

- LOA, Palaiseau, France: G. Lambert, J. Gautier, S. Sebbar, P. Zeitoun, ...
- MBI, Berlin, Germany: S. Eisebitt, C. von Korff Schmising ...
- IJL, Nancy, France: G. Malinowski, ...
- PSI, Villigen, Switzerland: F. Nolting, ...
- FERMI@Elettra, Trieste, Italy: F. Capotondi, M. Kiskinova ...
- FLASH, Hambourg, Allemagne: M. Kuhlmann, R. Treusch ...
- SOLEIL, Gif-sur-Yvette: N. Jaouen, ...

## GDRI XFEL-Science

- Prochaine réunion annuelle : 11 décembre 2017 à Paris
- Pour s'inscrire : [jan.luning@upmc.fr](mailto:jan.luning@upmc.fr)

