Time-resolved x-ray magnetic resonant scattering

Probing magnetization dynamics in the nanosecond-nanometer regime

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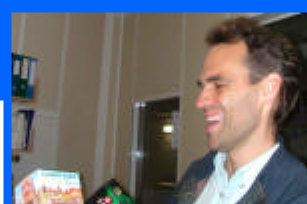
SRI 2003

Together with

POLARISATION DEPENDENT SOFT X-RAY SPECTROSCOPY
ID 8
ESRF
DRAGON
BEAM LINE

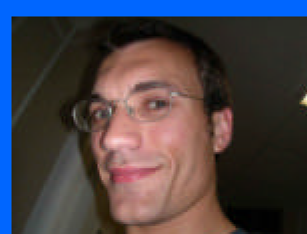
Nick Brookes



Jan Vogel
Lab L. Neel

Julio Camarero
UA Madrid

Marlio Bonfim
U. do Parana
Brazil



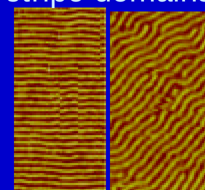
Jorge Miguel
UvA

Magnetism 1

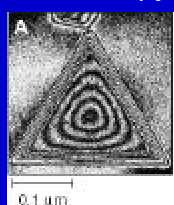
Length scales 0.1-100 nm

- domain wall width
- size of vortices
- size of stable particle magnetization
- correlation lengths in phase transitions

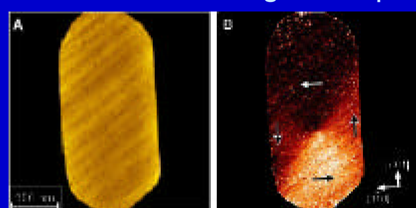
MFM on 100 nm stripe domains



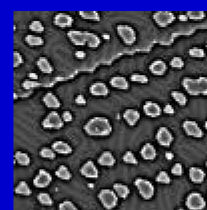
Lorentz microscopy



Vortex structures 8 nm STM antiferromagnetic tip

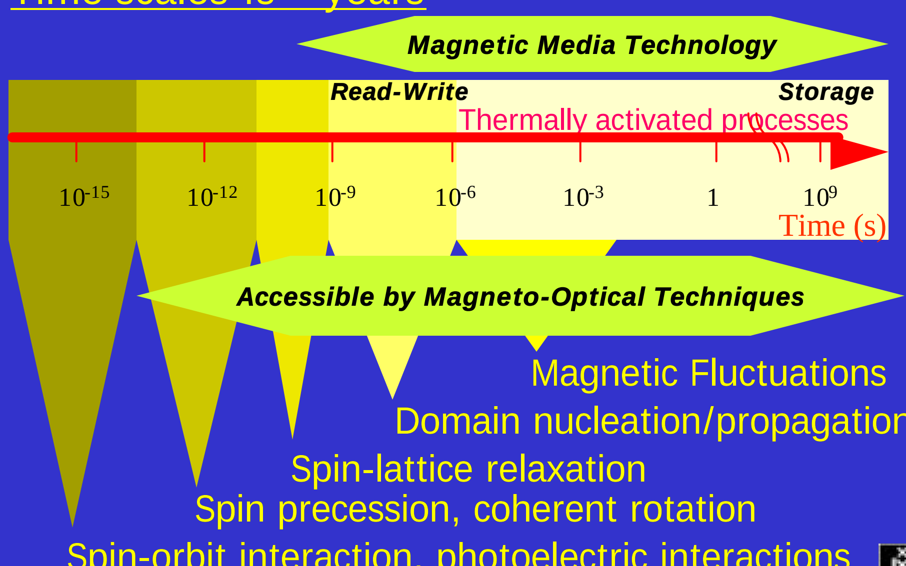


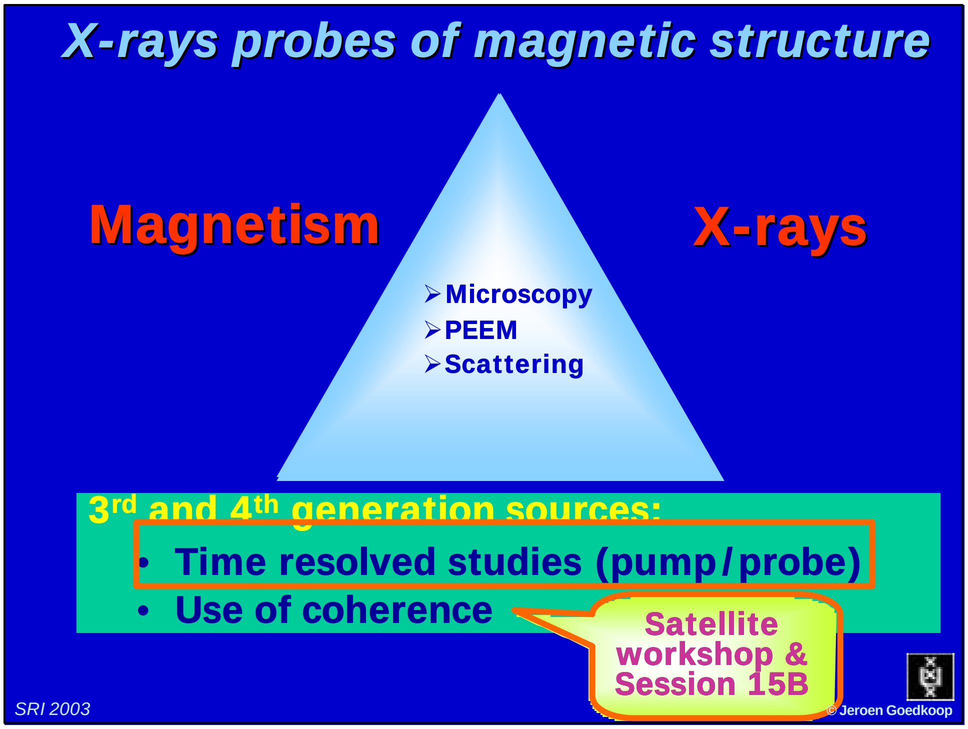
Superparamagnetic clusters 2-20 nm



Magnetism 2

Time scales fs – years




X-rays probes of magnetic structure
Magnetism
X-rays
➢Microscopy
➢PEEM
➢Scattering
3rd and 4th generation sources:
• Time resolved studies (pump/probe)
• Use of coherence
Satellite workshop & Session 15B
SRI 2003
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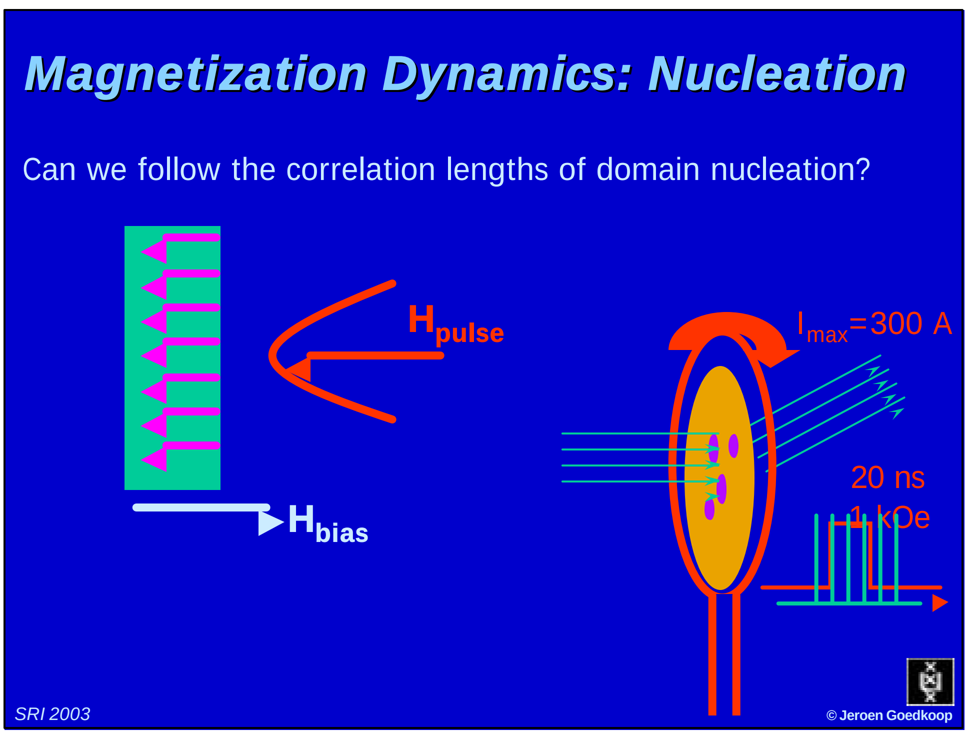
Magnetization Dynamics: Nucleation
Can we follow the correlation lengths of domain nucleation?
Hpulse
Hbias
Imax=300 A
20 ns
1 kOe
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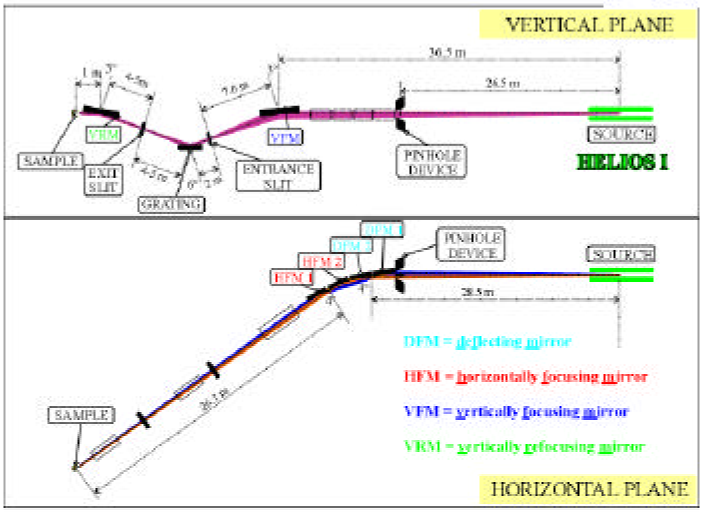
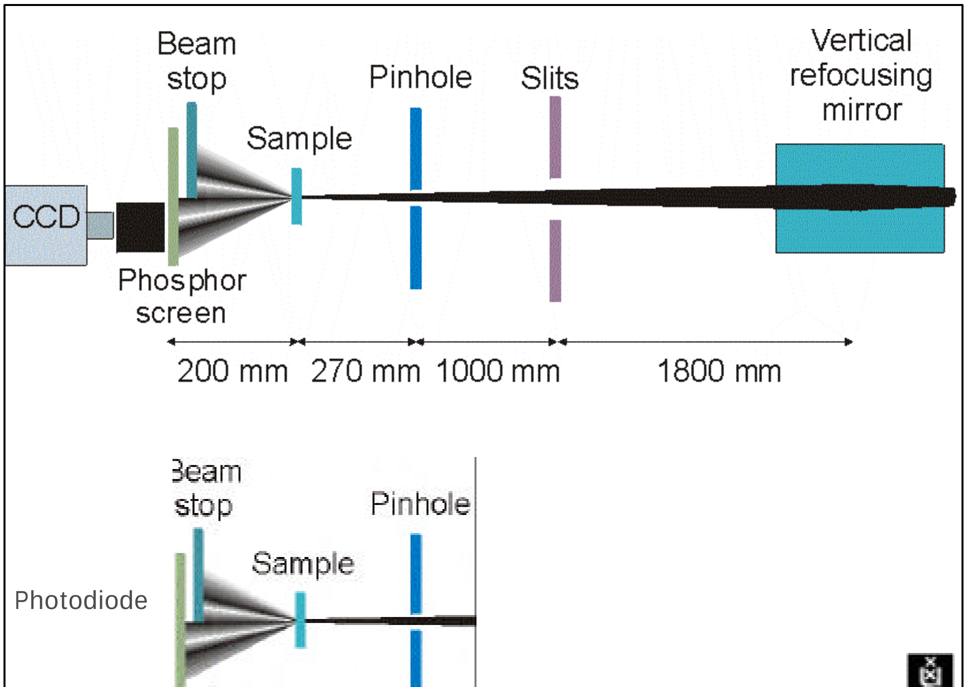
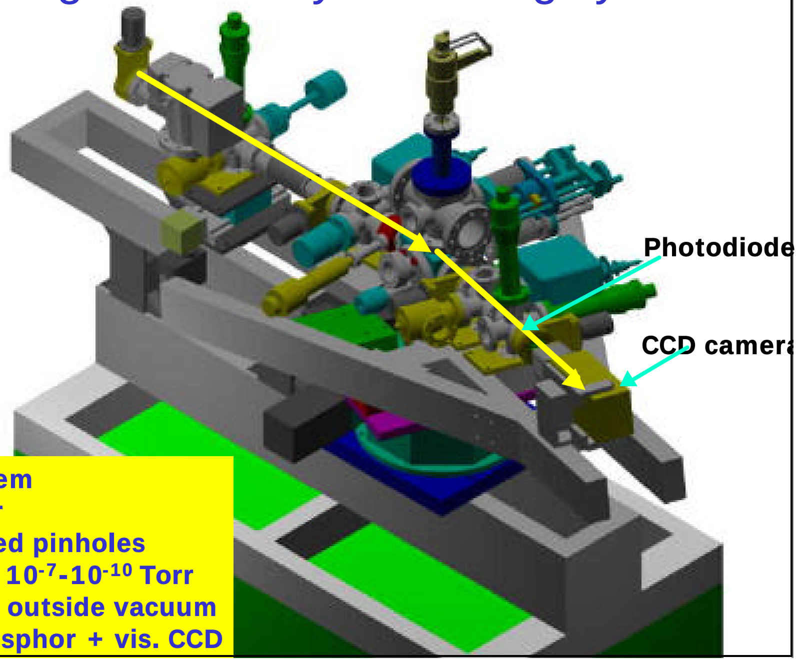
Grating monochromator beamline ID08 Dragon @ESRF



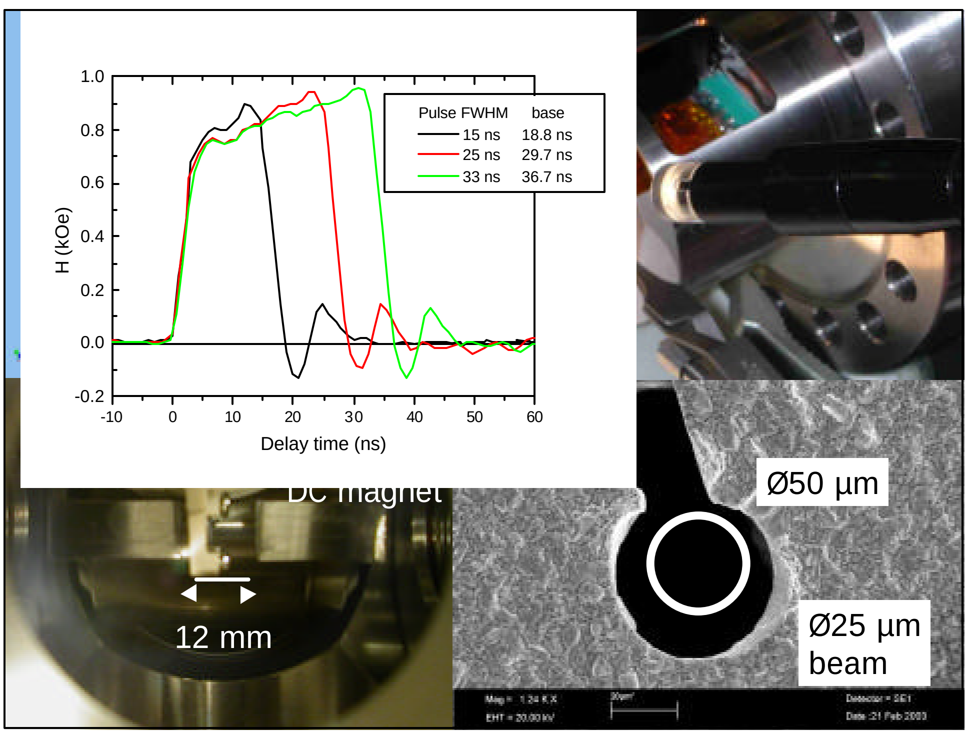


Small angle soft x-ray scattering system



SASXS system

- **modular**
- **optimized pinholes**
- **vacuum 10^{-7}-10^{-10} Torr**
- **motions outside vacuum**
- **P20 phosphor + vis. CCD**



amorphous-Gd_xFe_{1-x}

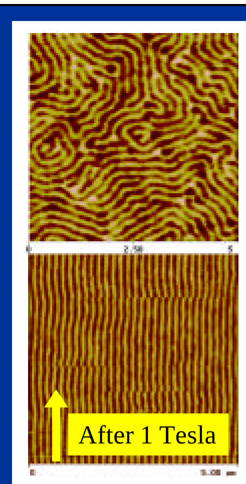
Ferrimagnet

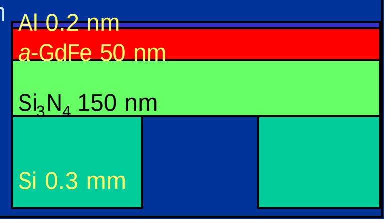
perpendicular anisotropy

Tuneable domain structure:

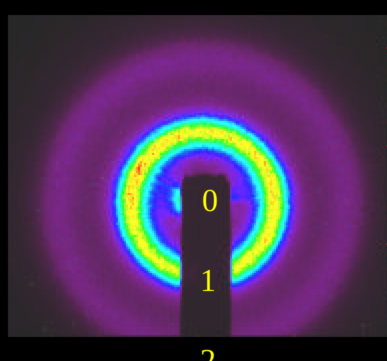
- Thickness
- Composition

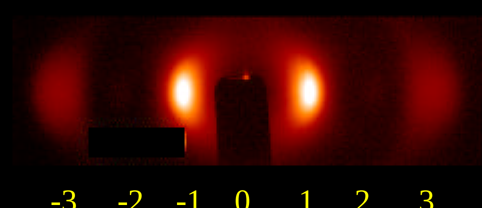
- MBE grown
- Substrate:
  - 150 nm Si_3N_4 membrane - transmission
- MFM: disordered stripes
- MOKE: typical stripe loop
- RBS, XRD, SQUID

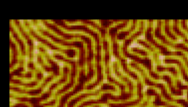


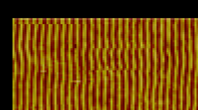


Diffraction patterns of disordered and aligned stripes





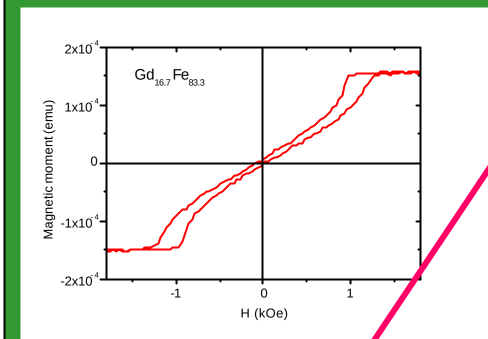




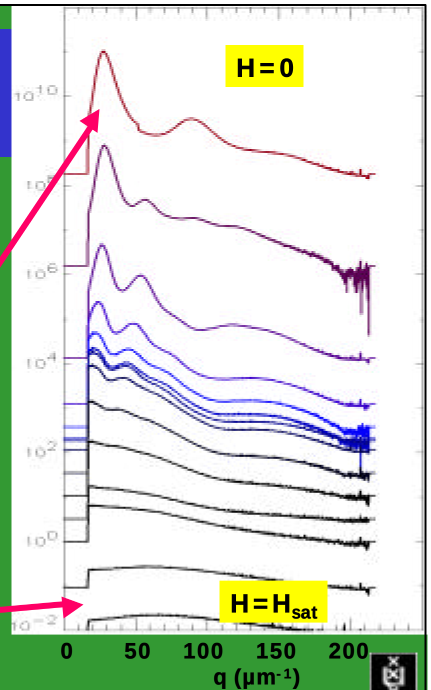
100 μm beam

Gd M_5 edge

Static field dependence sample 1

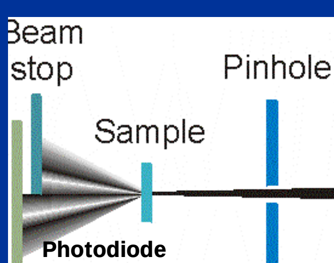


Transition from
stripe structure factor to
reverse domain form factor



1. *q* integrated intensities

- Measure total scattered intensity with diode
- Disentangle scatter and dichroic absorption:



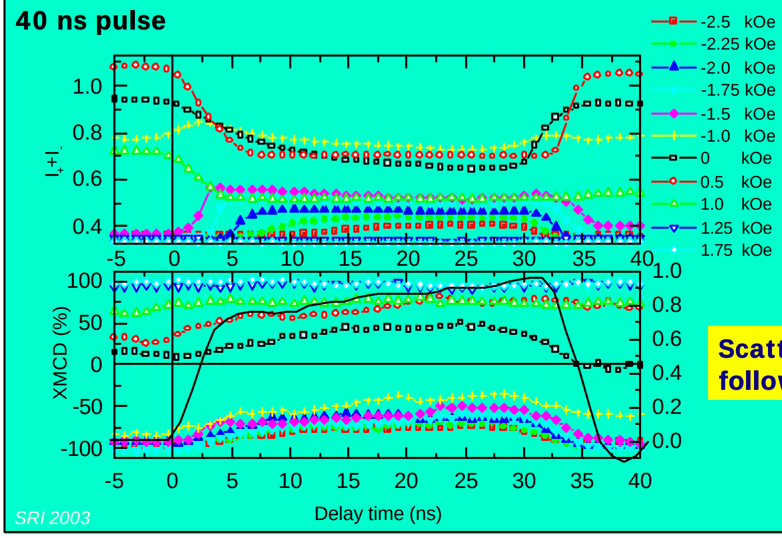
$$M_{rel} = \frac{I^{+}_{scat} - I^{-}_{scat}}{I^{+}_{scat} + I^{-}_{scat}}$$

$$I_{scat} = I^{+}_{scat} + I^{-}_{scat}$$

q-integrated spectra vs. bias field

sample 1

40 ns pulse



Scatter and M follow field

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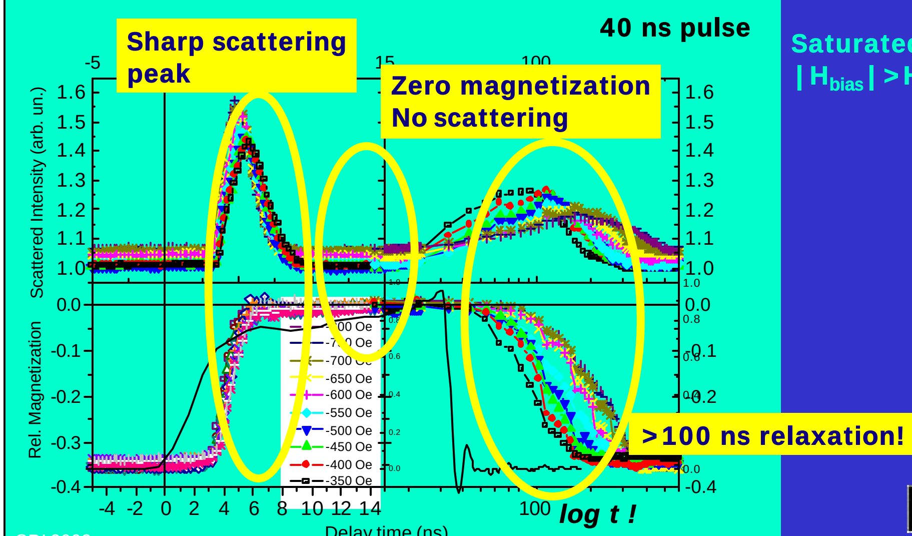
q-integrated spectra vs. bias field

sample 2

40 ns pulse

Saturated $|H_{bias}| > H_{sat}$



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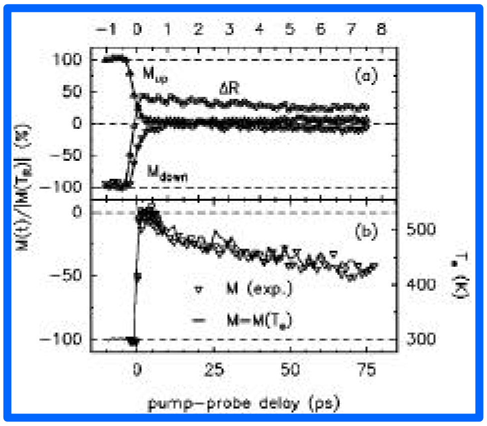
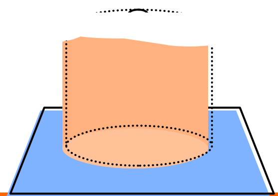
fs LASER pumping





100 fs pulse @ 800 nm
1000 µm pump, 100 µm probe

Hohlfeld et al., Nijmegen
fs laser pulse reversal in GdFeCo
PRB 65 012413

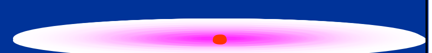
Relaxation follows Bloch equation

$$\frac{dM(t)}{dt} = \frac{-M_0[T(t)] - M(t)}{\tau}$$

2. *q*-resolved scattering

scintillator + visible CCD camera

- Single bunch ÷20
- 25 µm pinhole ÷80
- detector efficiency ÷100

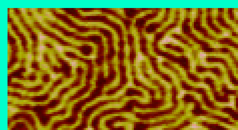


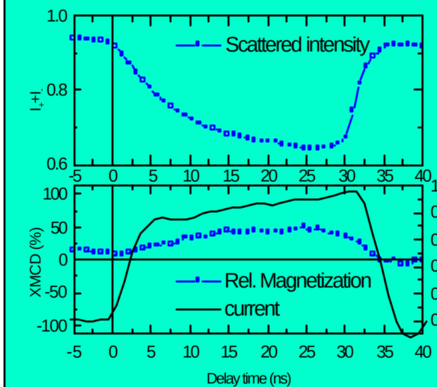
>>Down by factor 16000 in counts

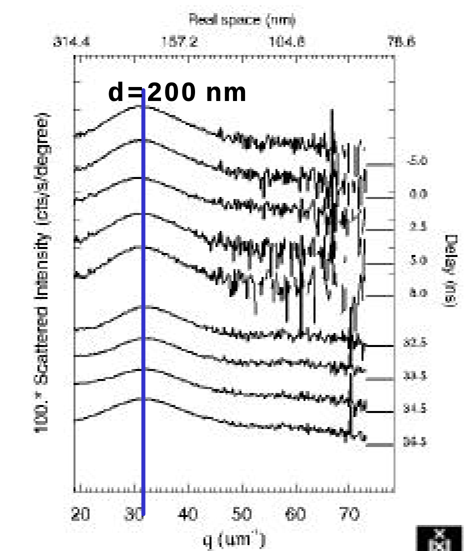
Two cases

Remanent (Hbias=0)	**Domain wall motion**
Saturated (Hbias=Hsat)	**Nucleation**

sample 1 $GdFe_5$: remanent







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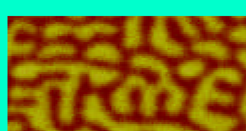
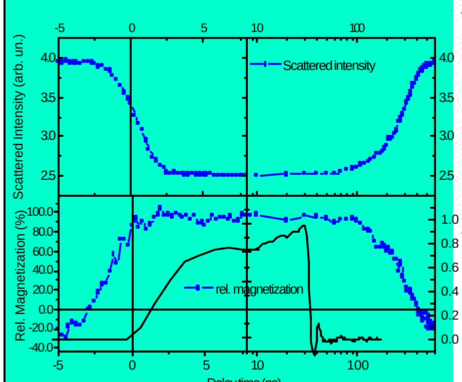
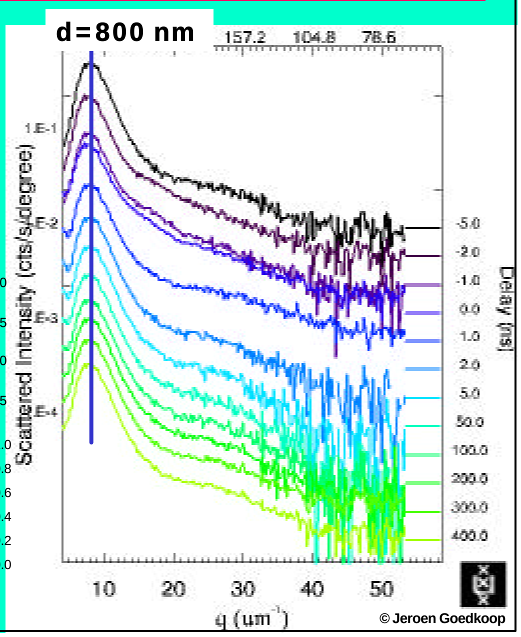
sample 2: $GdFe_{81.6}$: remanent







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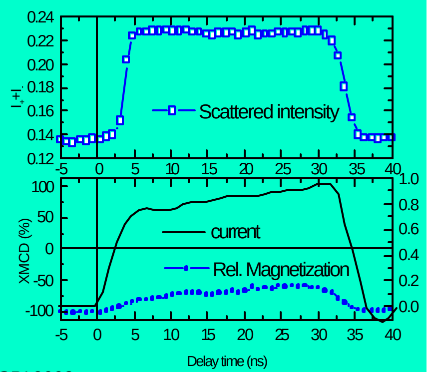
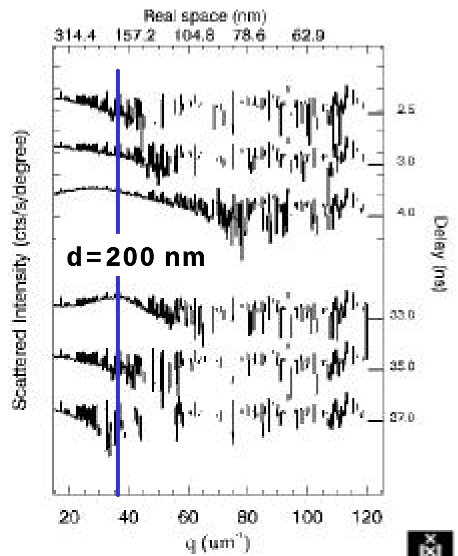
sample 1 $GdFe_5$: saturated





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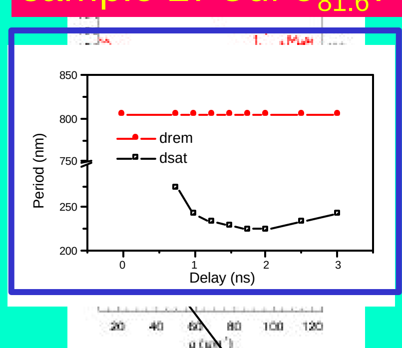
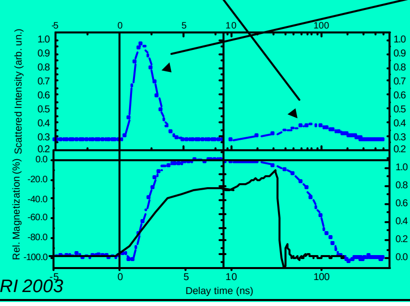
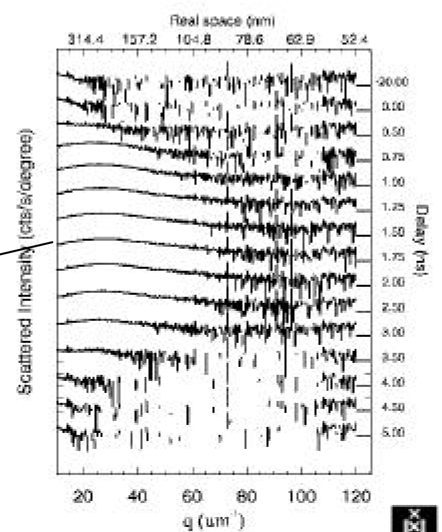
sample 2: $GdFe_{81.6}$: saturated







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Conclusions

- ☺ TR magnetic scattering viable and useful technique for ns/nm scale dynamics
- ☺ Simultaneous measurement of
  - ➢ magnetization
  - ➢ domain wall volume
  - ➢ domain sizes
- ☺ Strongly different response for two slightly differing samples
  - ➢ sample 1: follows pulse
  - ➢ sample 2: M $\rightarrow$ 0, relaxation over > 100 ns
  - ➢ magnetic heating?
  - ➢ When domains present, their size/distance stays constant!

Future

- sub-ns magnetic pulses can be made
- Requires small spot size, high dynamic range CCD's

- Requires few-bunch machine operation
- Bunch length of 20 ps desirable
- ERL and FEL will open up new range of nanometer-scale magnetism
  - spin lattice interactions
  - coherent rotation