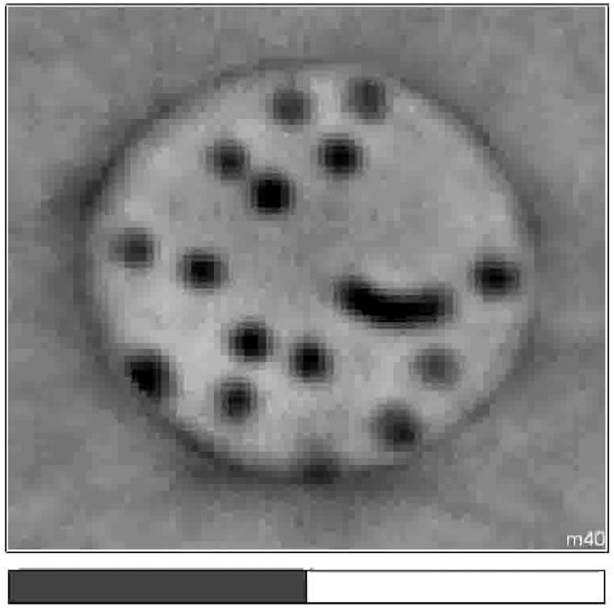
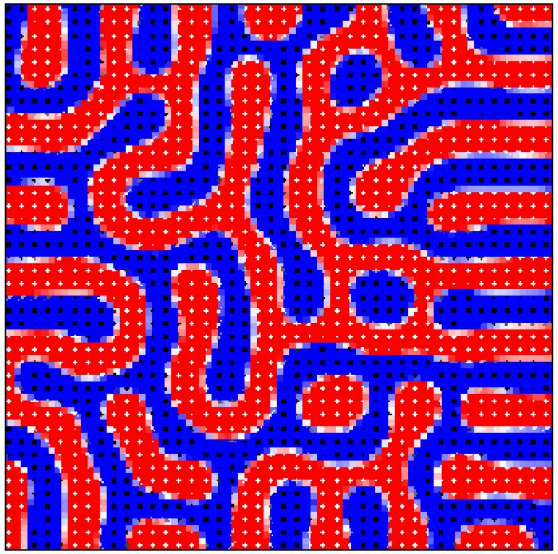
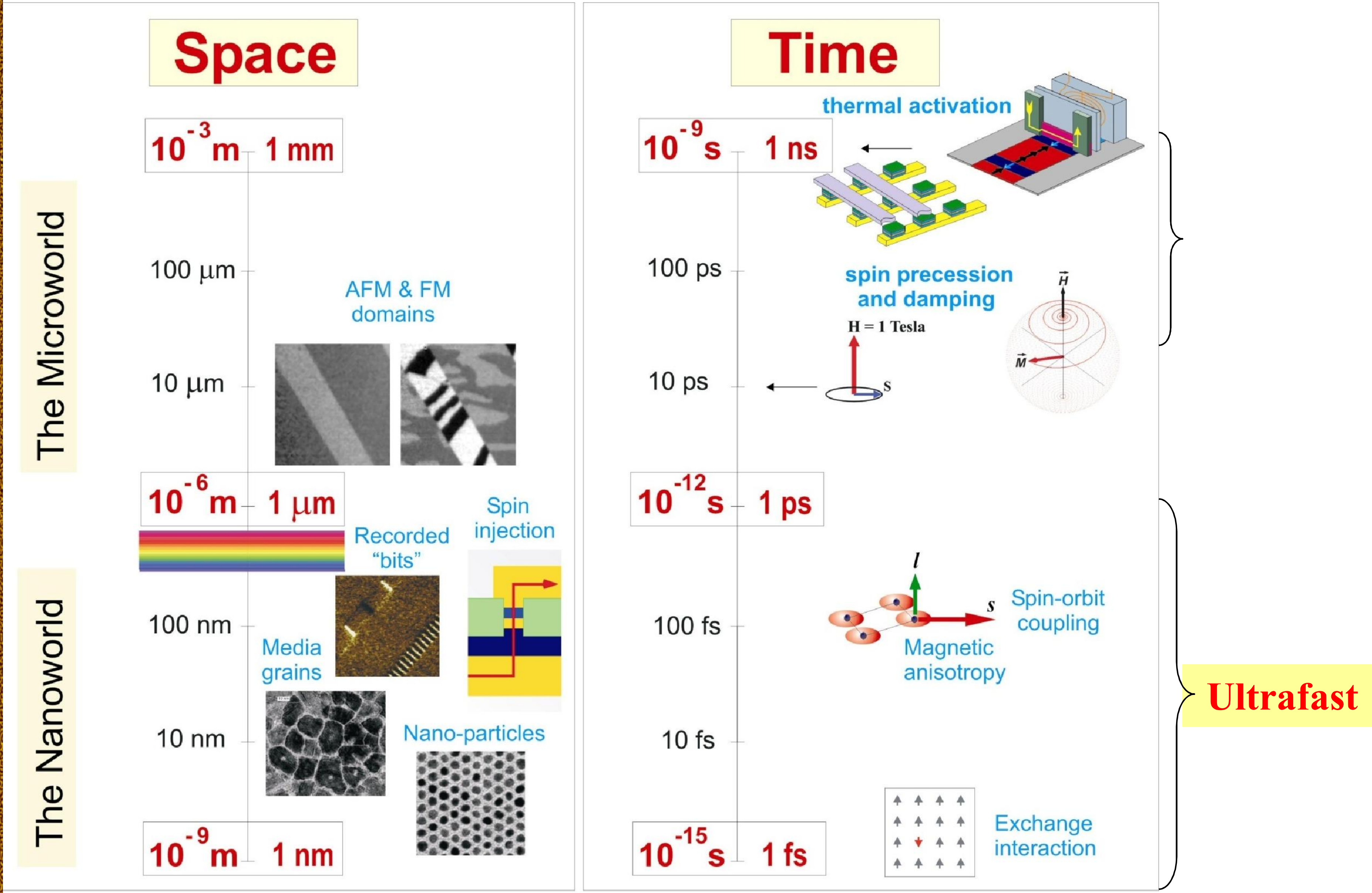
Magnetism at Nanoscale: Nano-small meets Ultra-fast



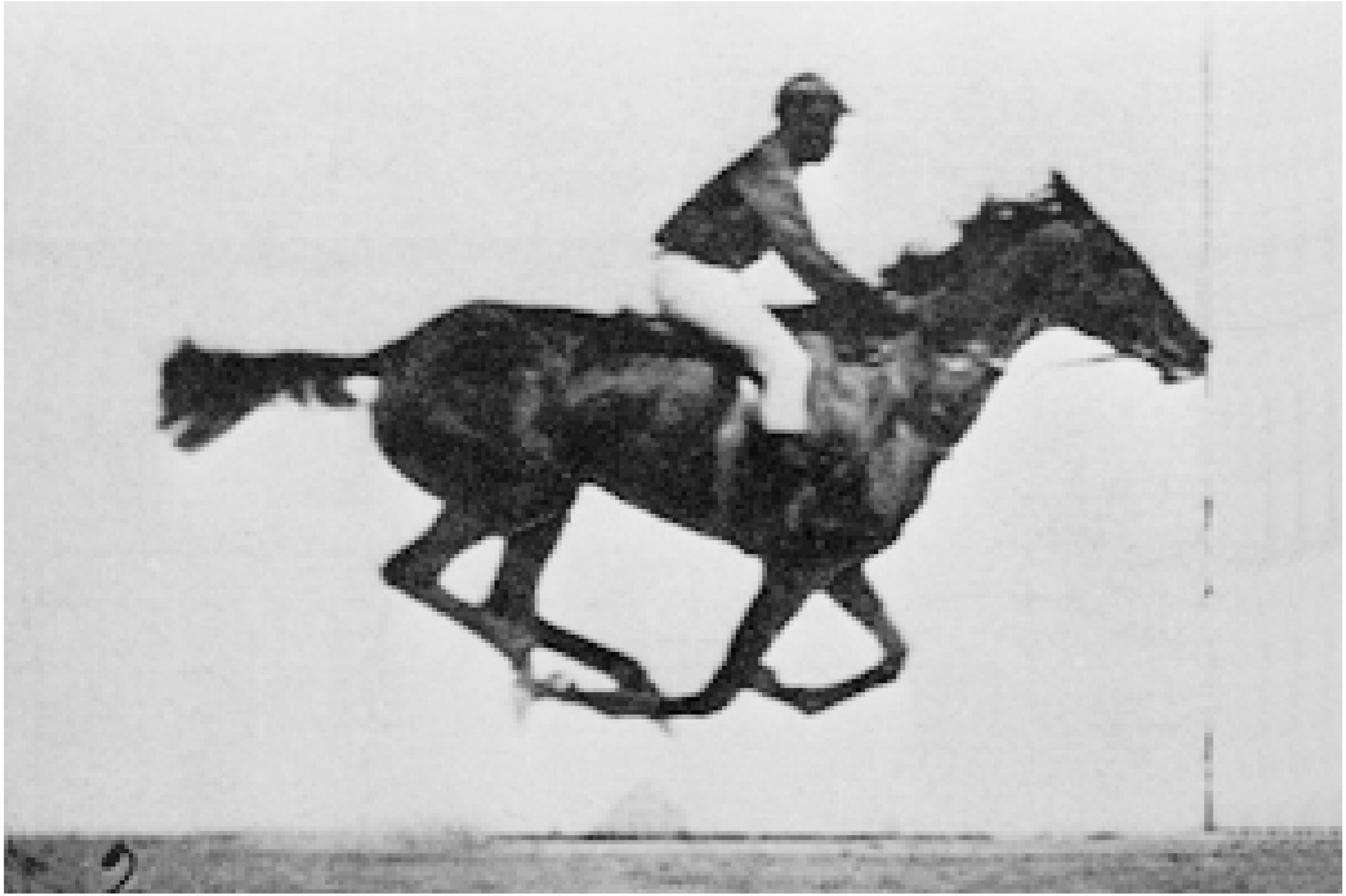


Jyoti Mohanty

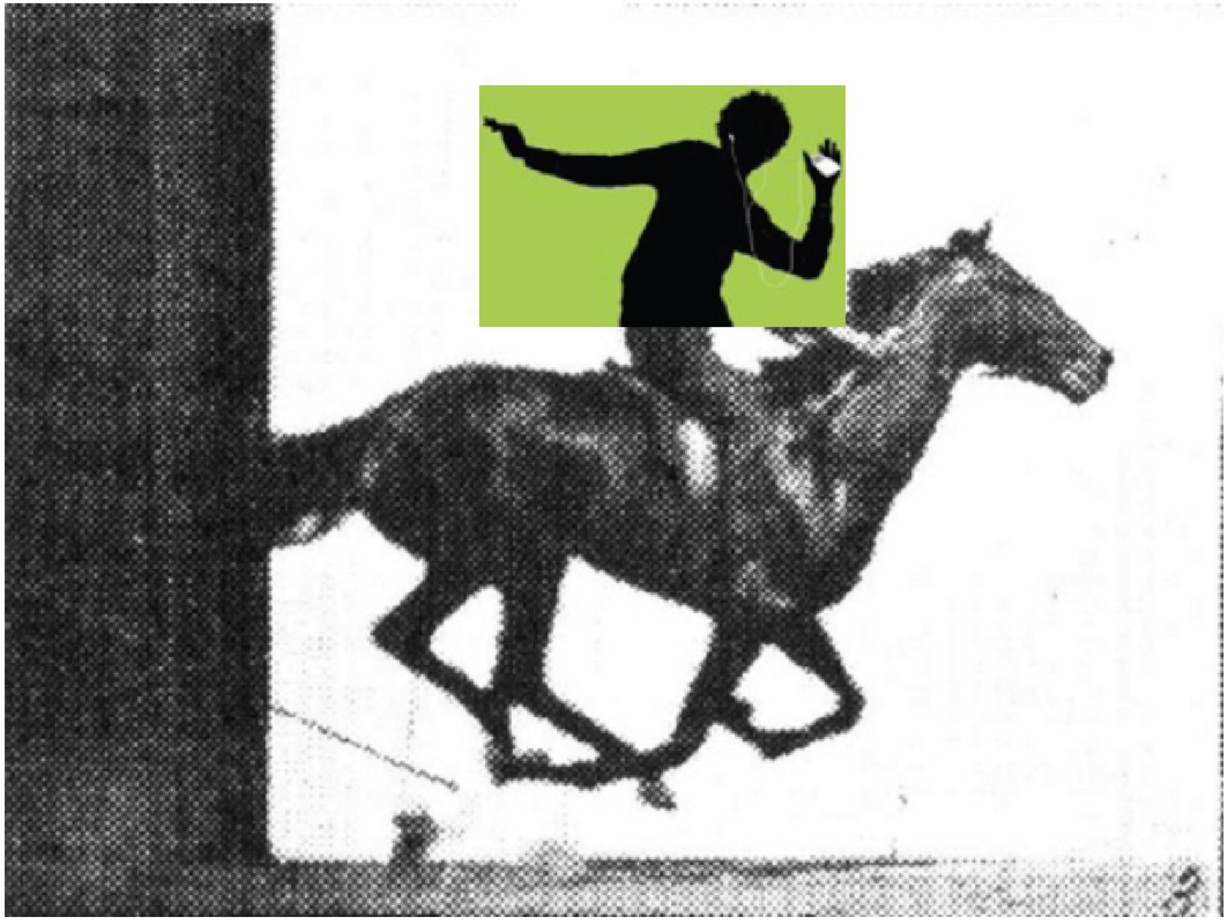
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad



Note: Δt (fs) = 4 / ΔE (eV)



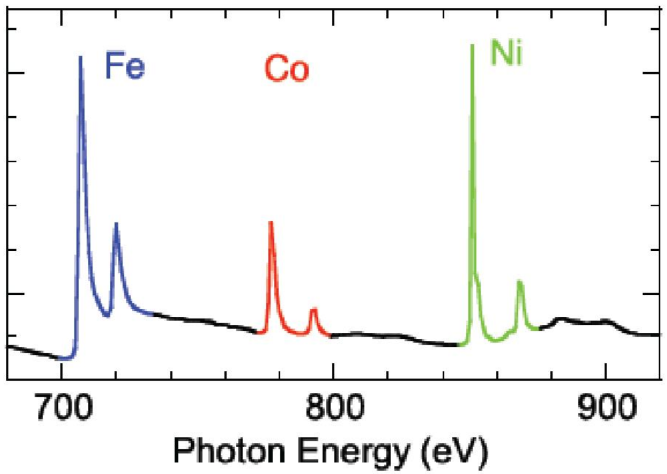
$(10^{-3}\,s;\ 10^{-3}\,m) \rightarrow (10^{-15}\,s;\ 10^{-9}\,m)$



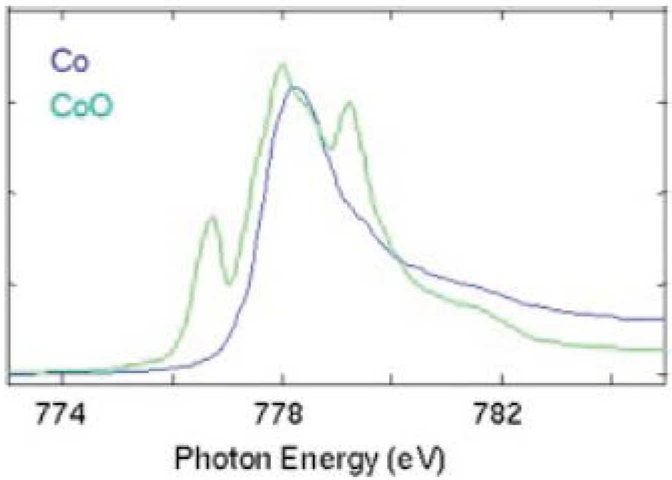
Why use X-rays?

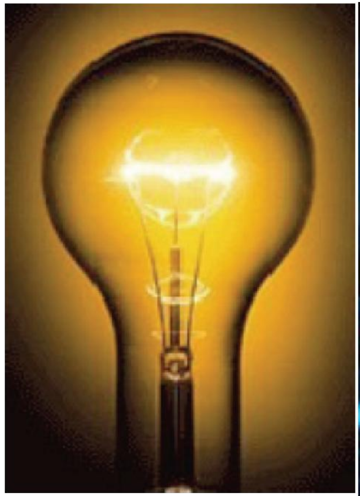
- See the invisibles
  (buried interface)
- Nano-scale resolution
- Quantitative information
- Photon-in photon-out:
  applied E or B
- Weakly interacting
  Nanomagnet are not switched
- Coherence properties
  Dynamic properties

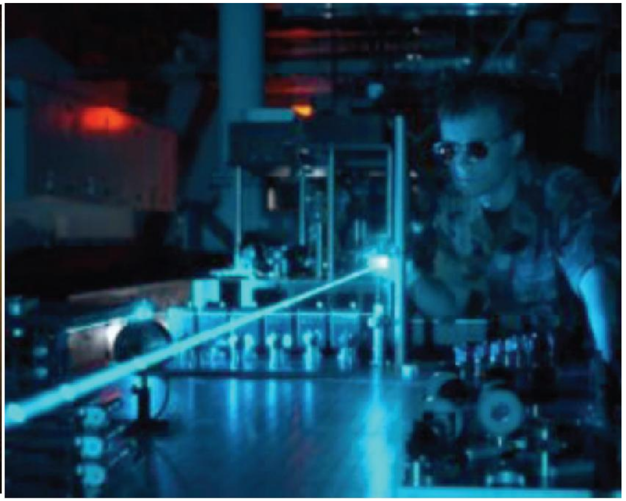
Elemental sensitivity



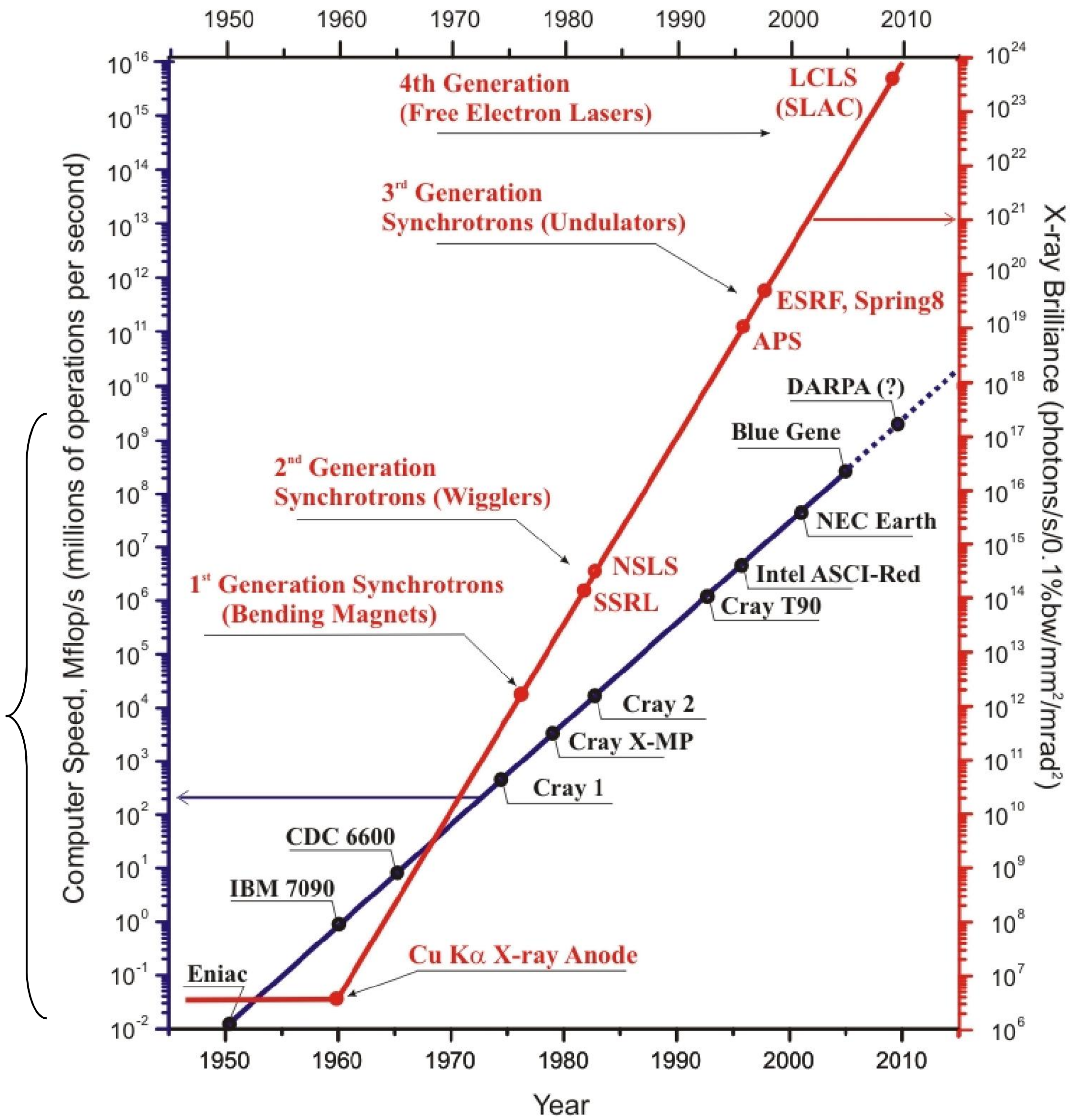
Chemical sensitivity







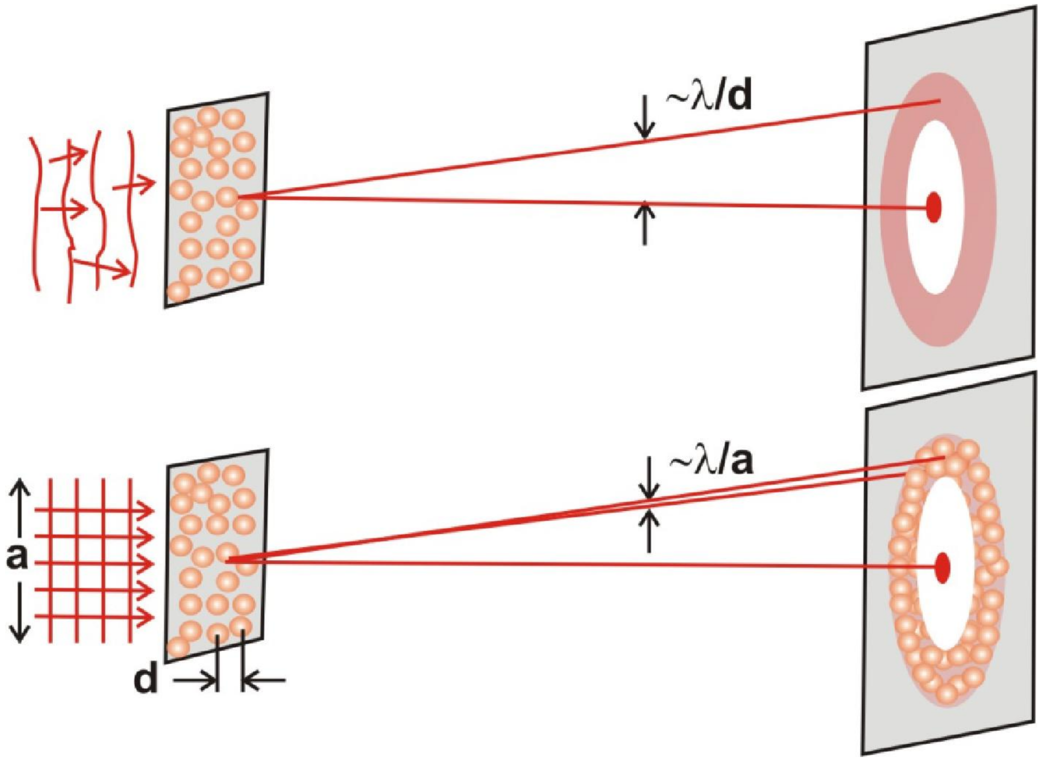
Brilliance is Coherence



12 orders of magnitude In 6 decades

18 orders of magnitude In 5 decades!

Coherent X-ray Scattering



- Coherence length smaller than illumination area
- Information about sample statistics

- Coherence length larger than illumination area
- Information about true sample structure

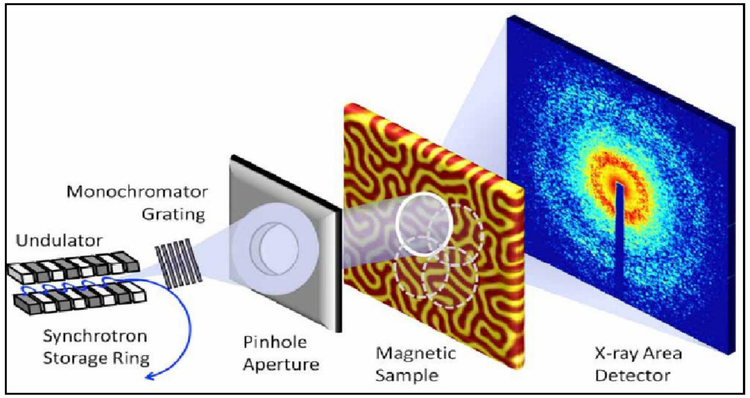
❖ longitudinal(temporal) $\sim\lambda^2/\Delta\lambda$

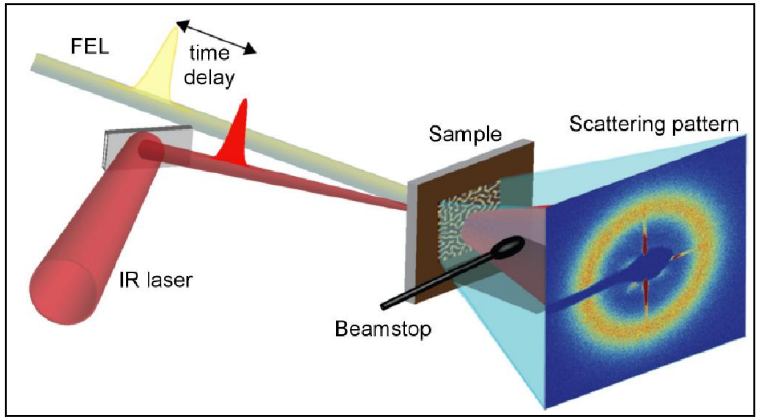
❖ transverse (spatial) $\sim L.\theta$

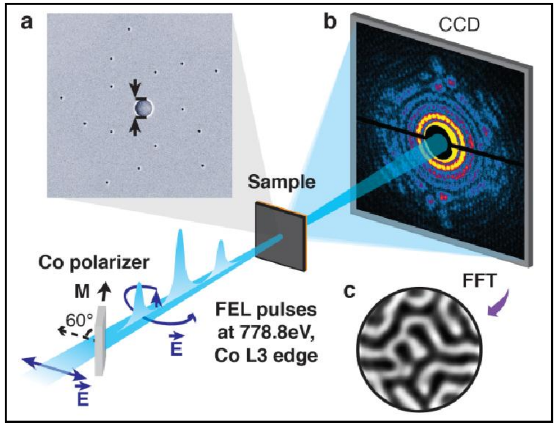
$$d_S.\theta=\lambda/2\pi$$

Application:

- Sample fingerprint
- Dynamics
- Imaging







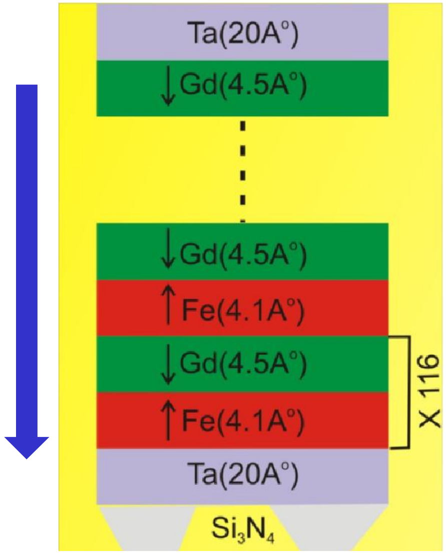
- Nanoscale dynamics
- Lensless imaging

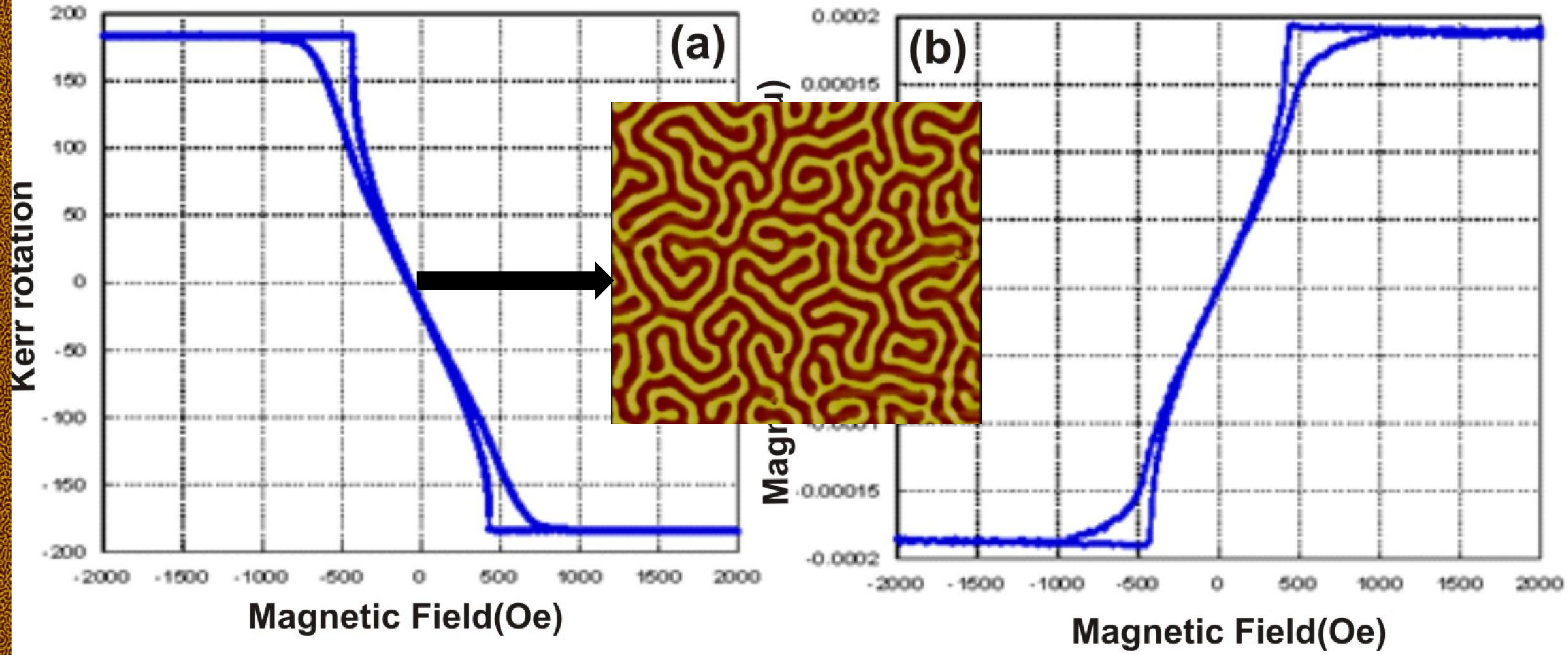
- Ultrafast Demagnetization

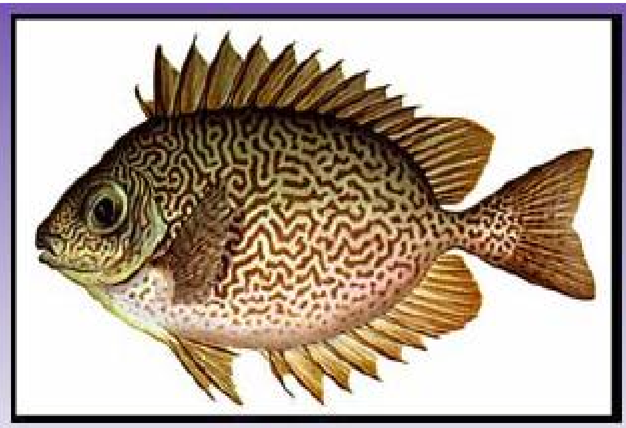
- Single-shot Imaging

Magnetic Multilayes

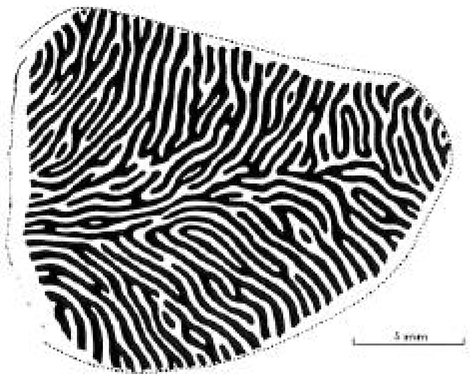
- ❖ Sputtering: Fe (0.44 Å /sec.) and Gd (1.82 Å/sec.)
- ❖ Perpendicular magnetic anisotropy (PMA)
- ❖ Stripe domains: shape and surface anisotropy energies are roughly equal
- ❖ Domain Dynamics and intermittent switching



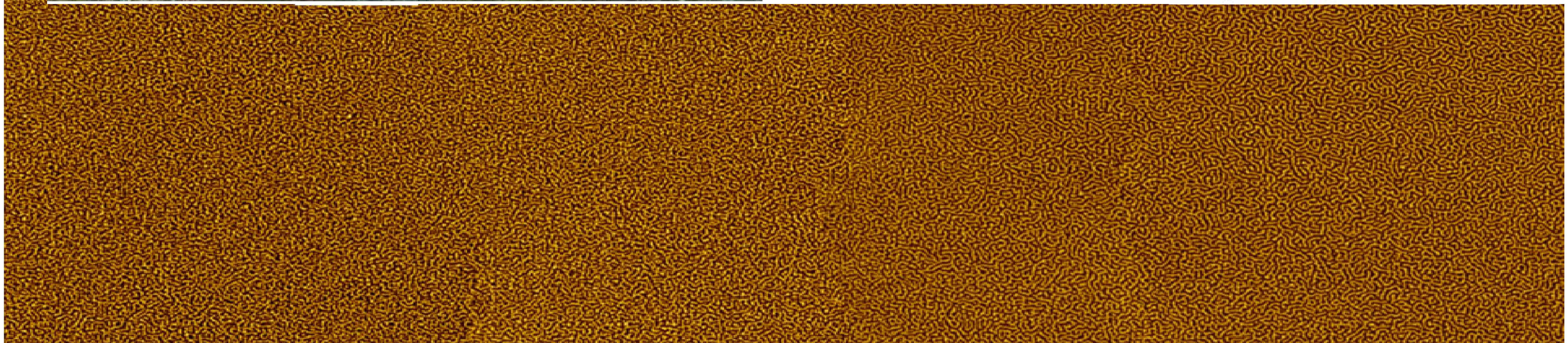




Vermiculated rabbitfish

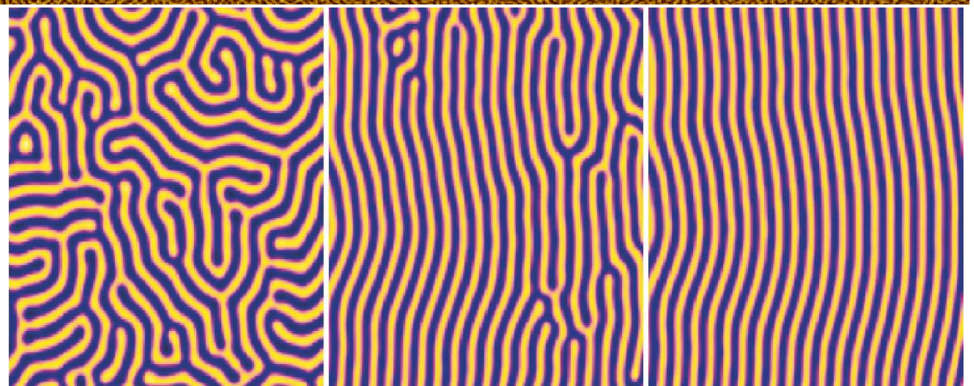


Ocular dominance stripes
(cat brain)

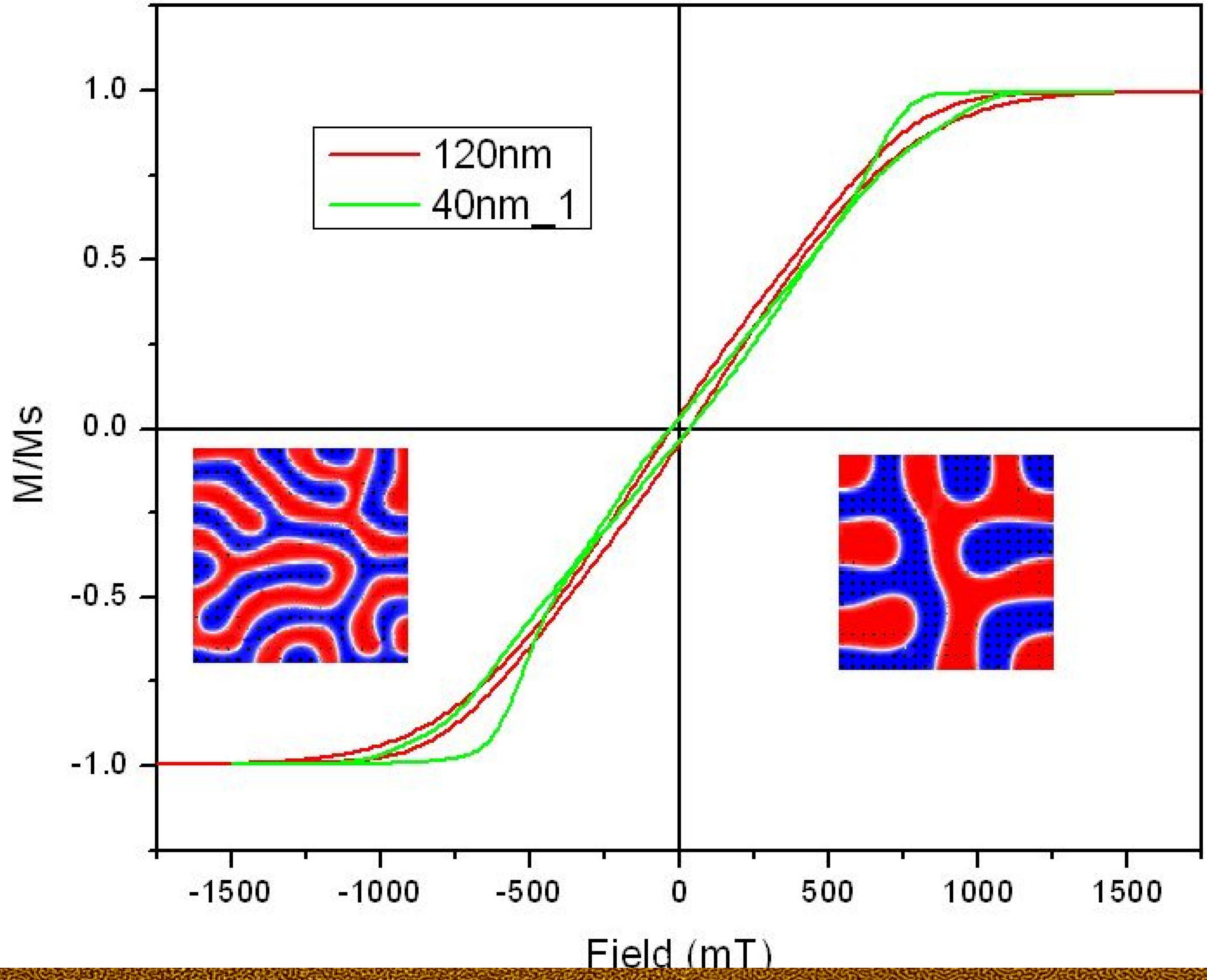


Template guided block copolymer

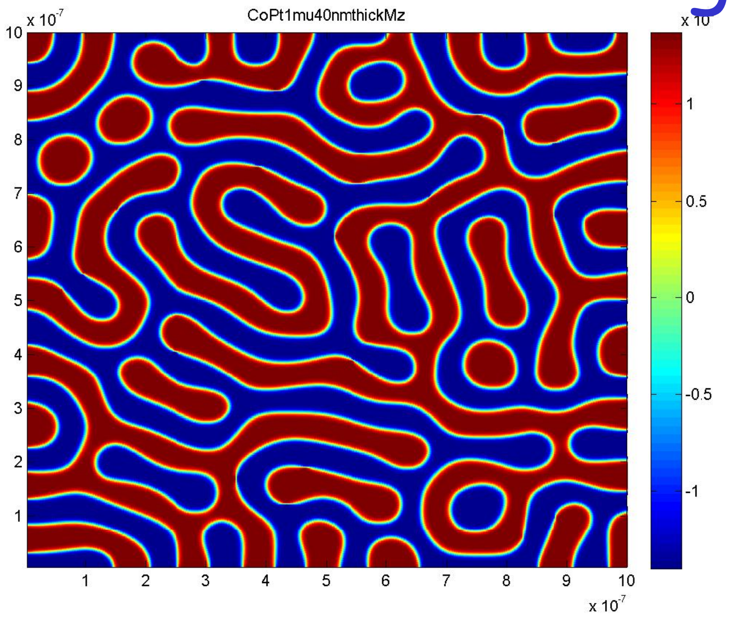
- Magnetic data storage
- Nanoscale electronics
- High efficient membrane for energy

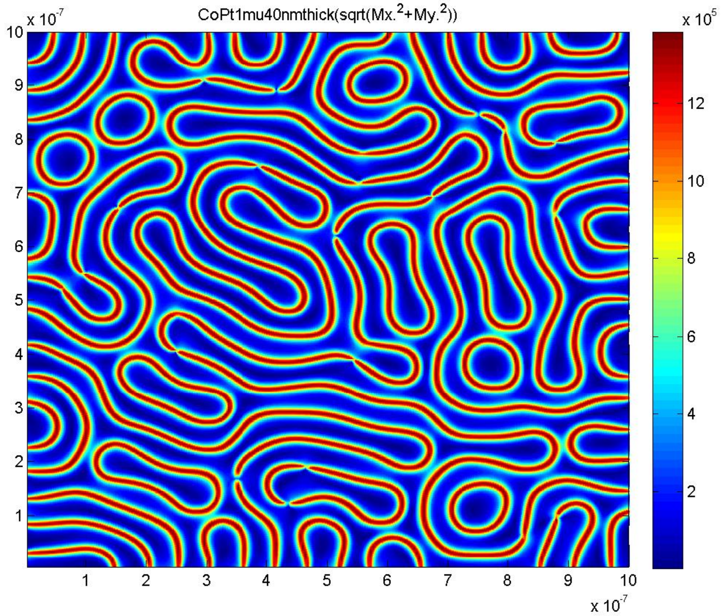


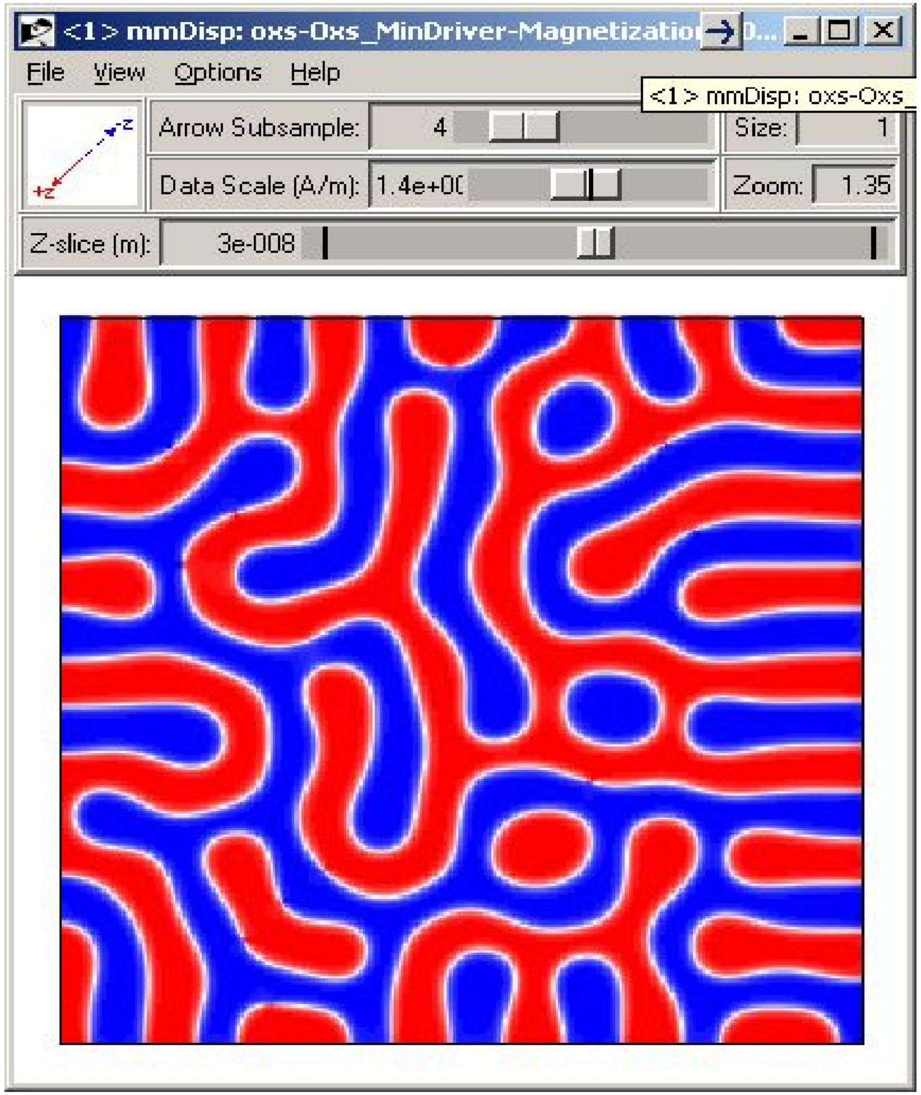
Micromagnetic Simulation



Micromagnetic Simulation

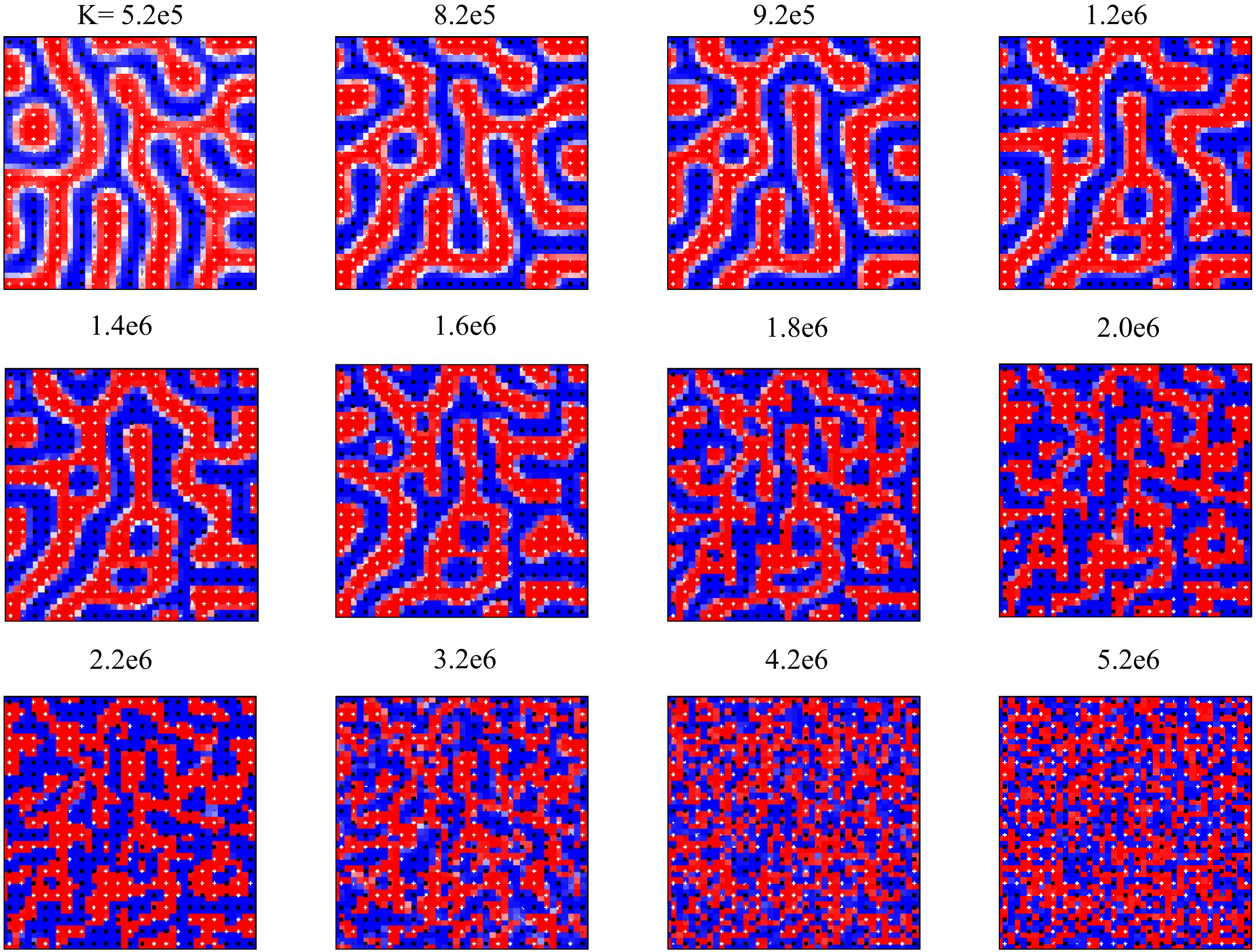




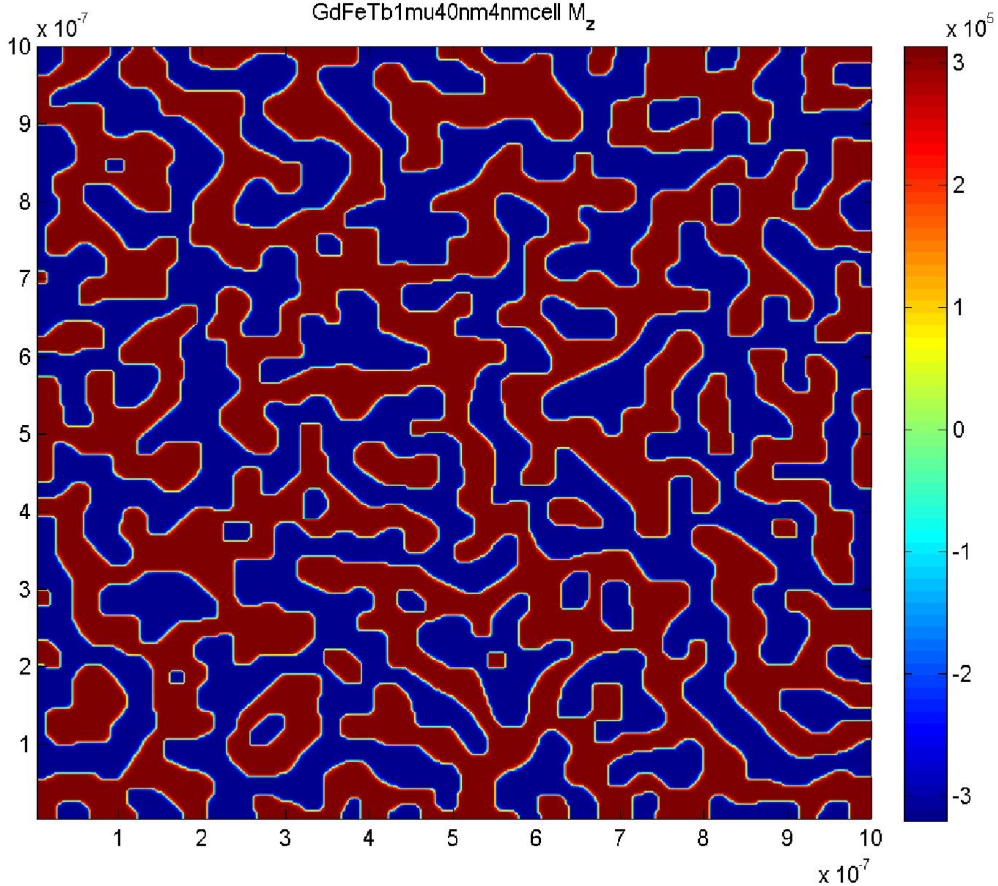


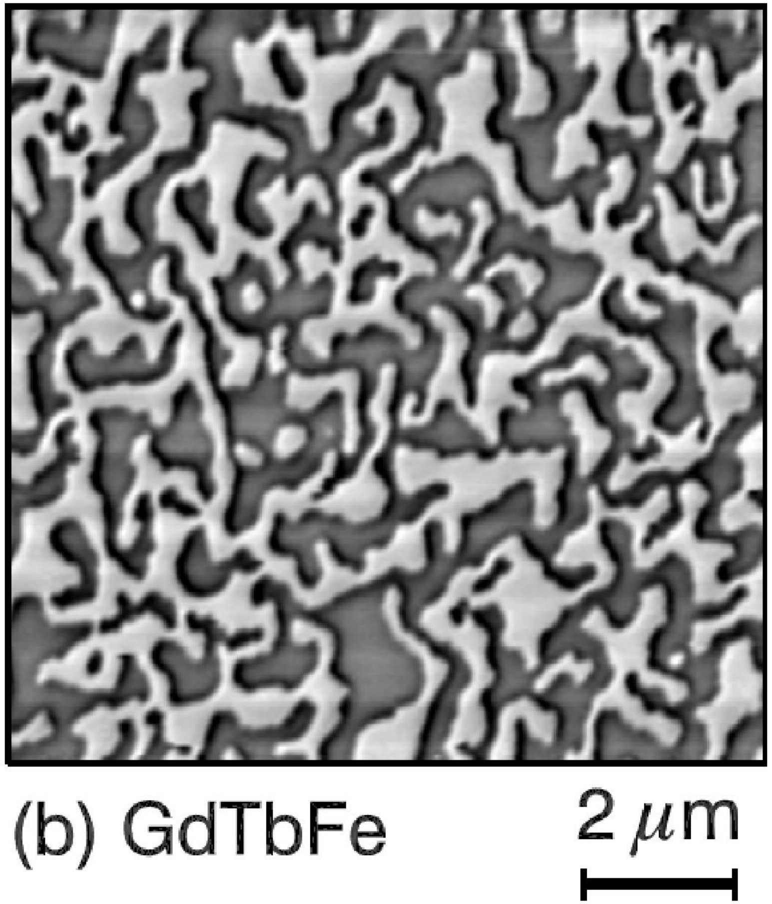
Perpendicular Anisotropy vs. Domain size in CoPt

500x500nm



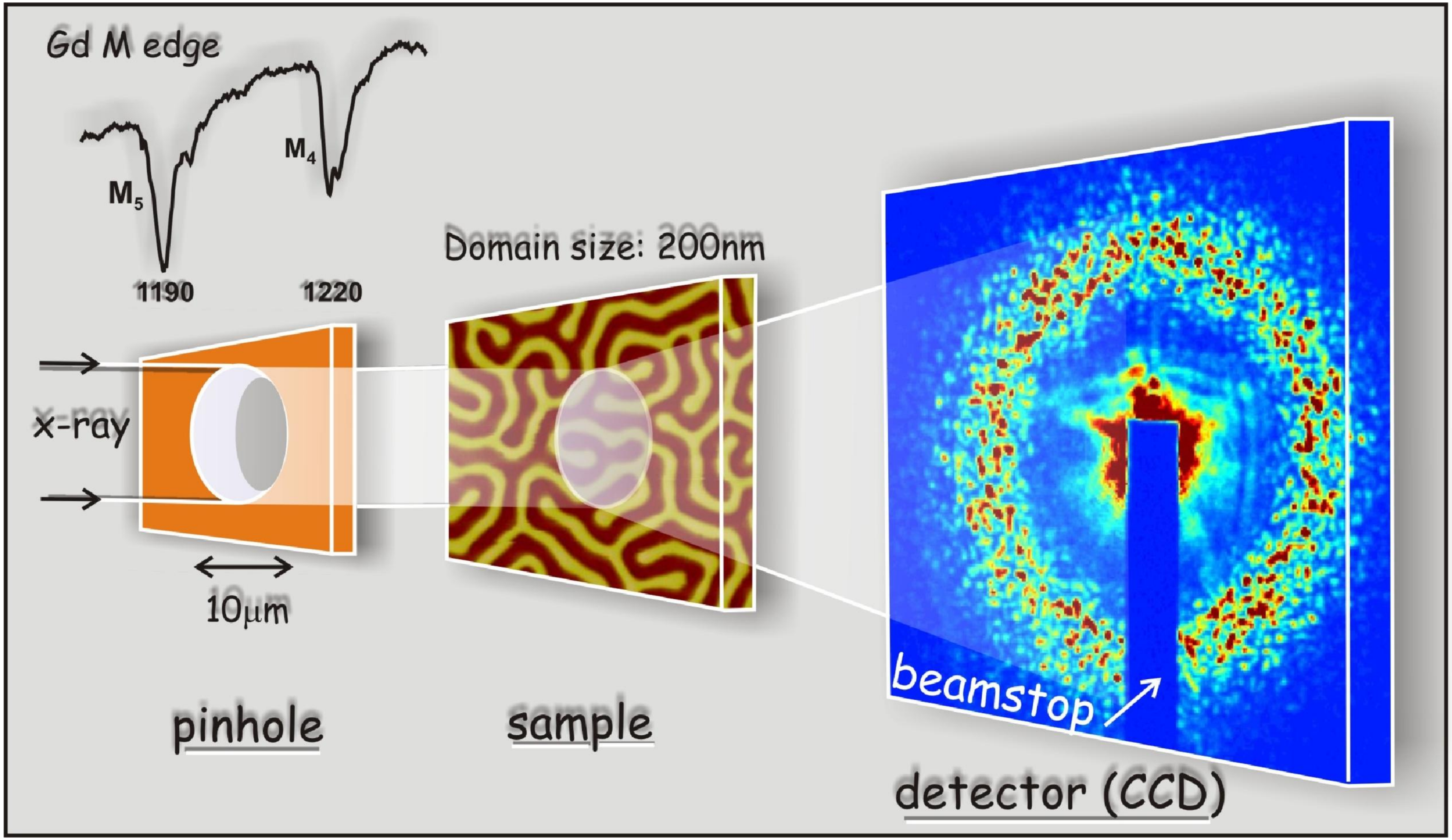
GdFeTb(40nm thick 4nm cell)



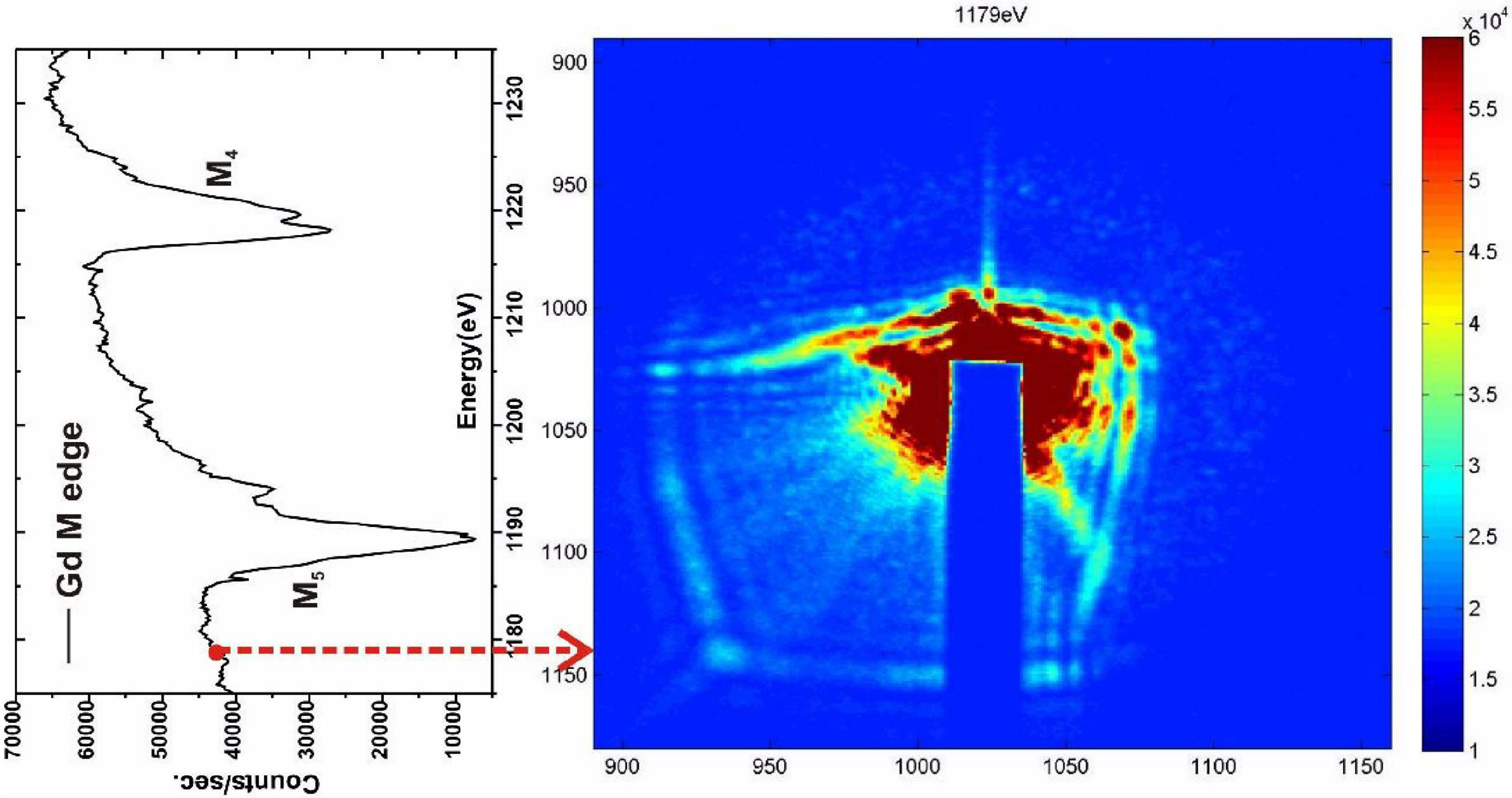


(b) GdTbFe

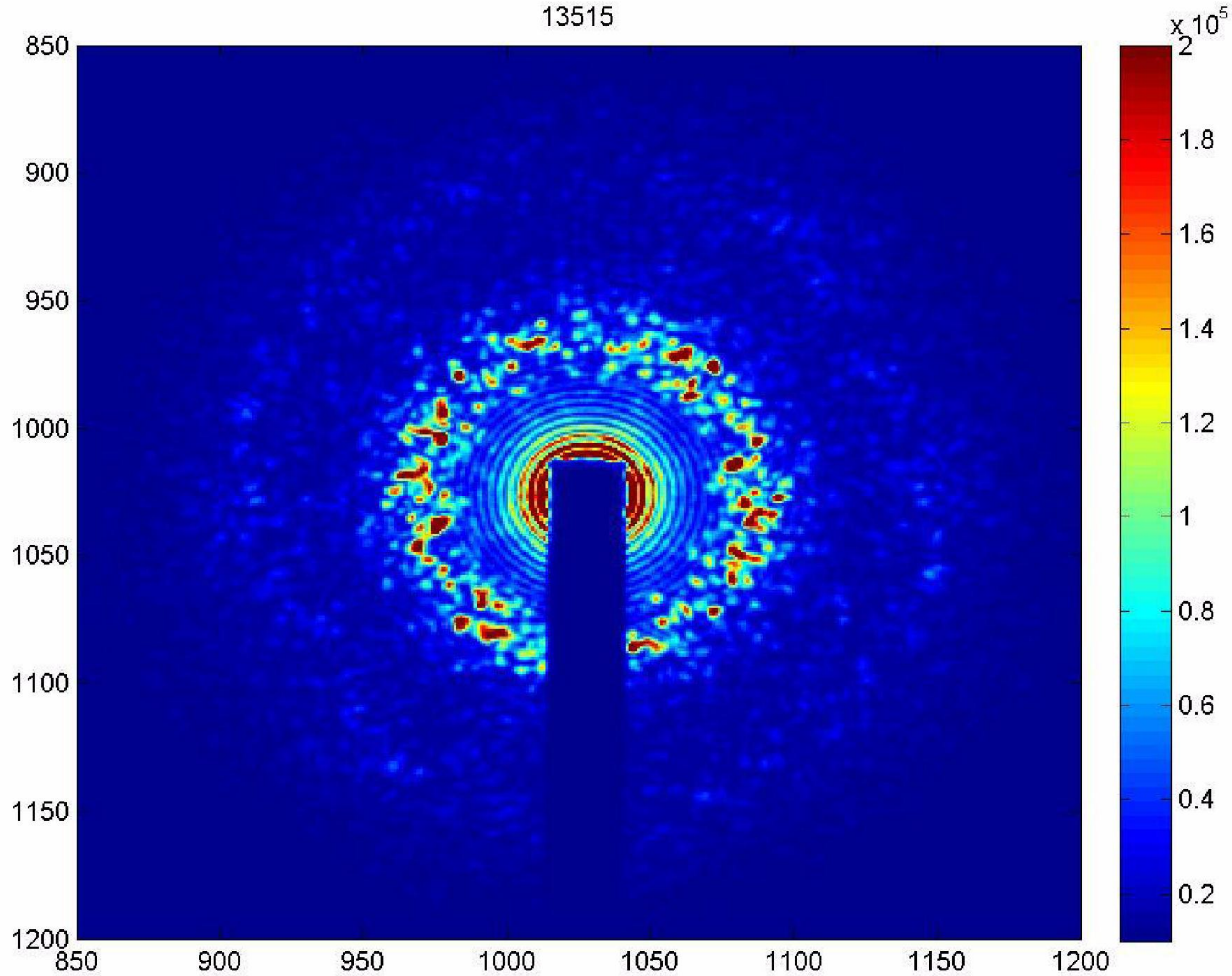
Coherent Resonant Magnetic Scattering



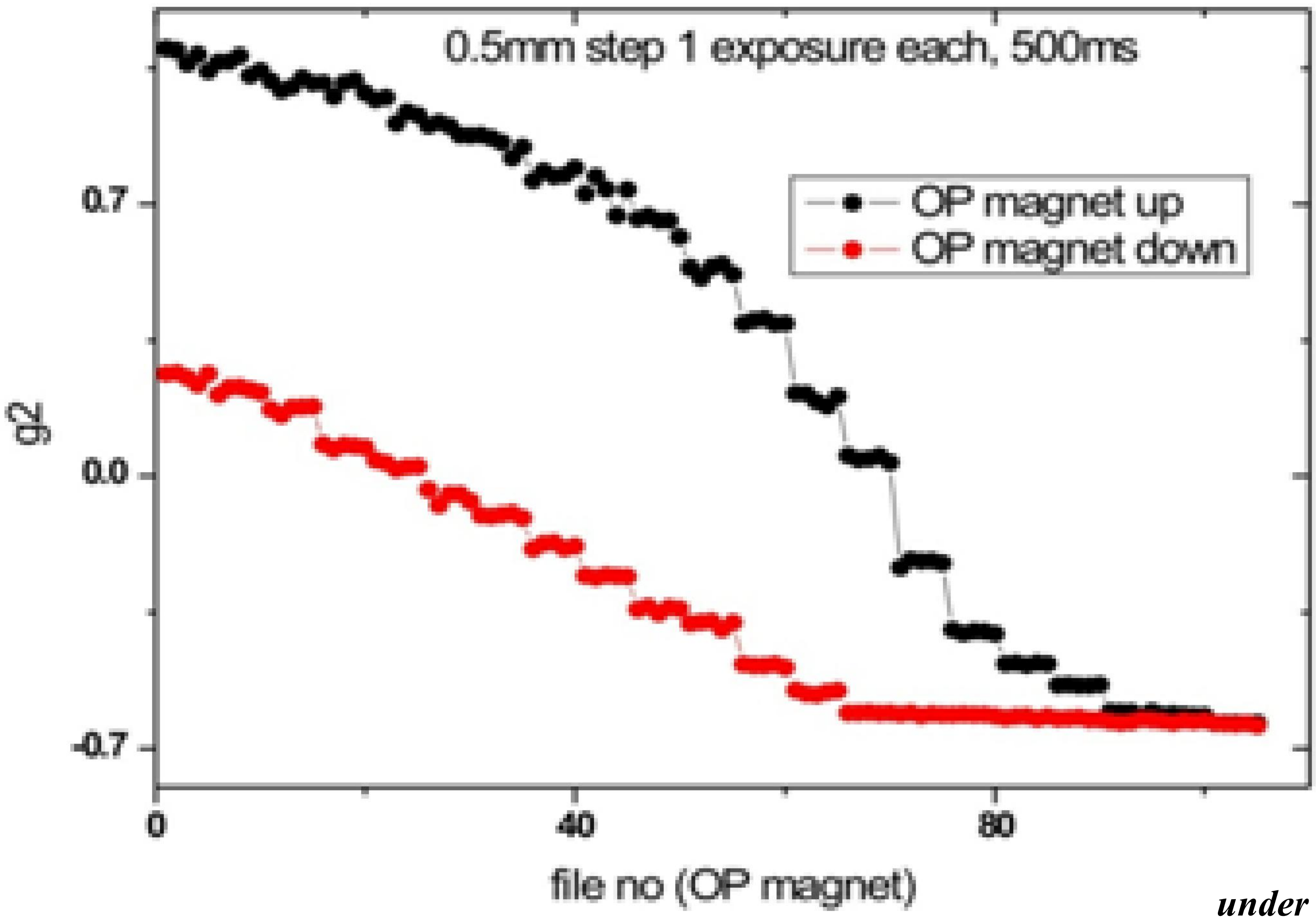
Resonant Magnetic Scattering



out-of-plane (OOP)

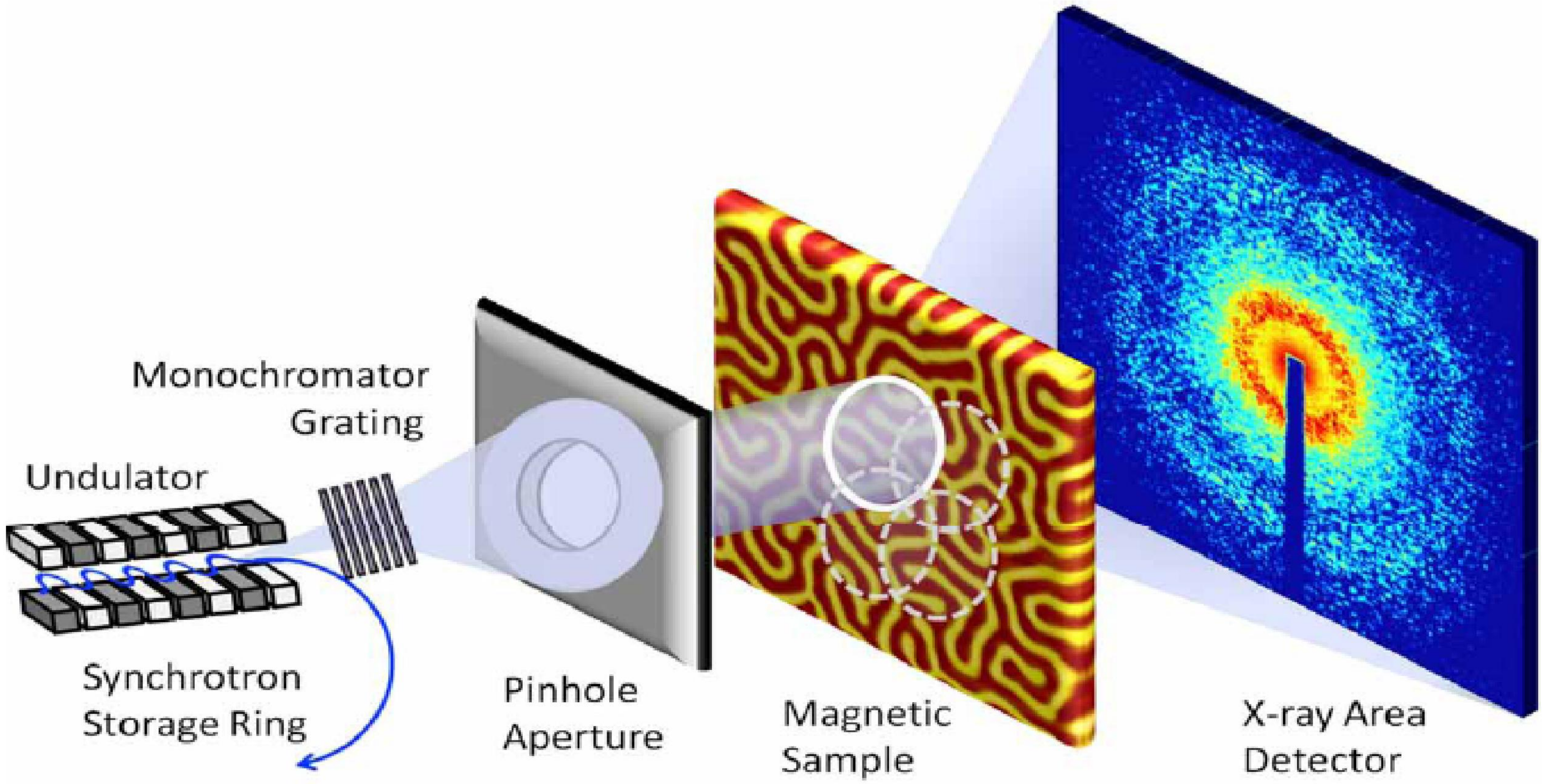


Magnetic Memory
(Barkhausen noise)

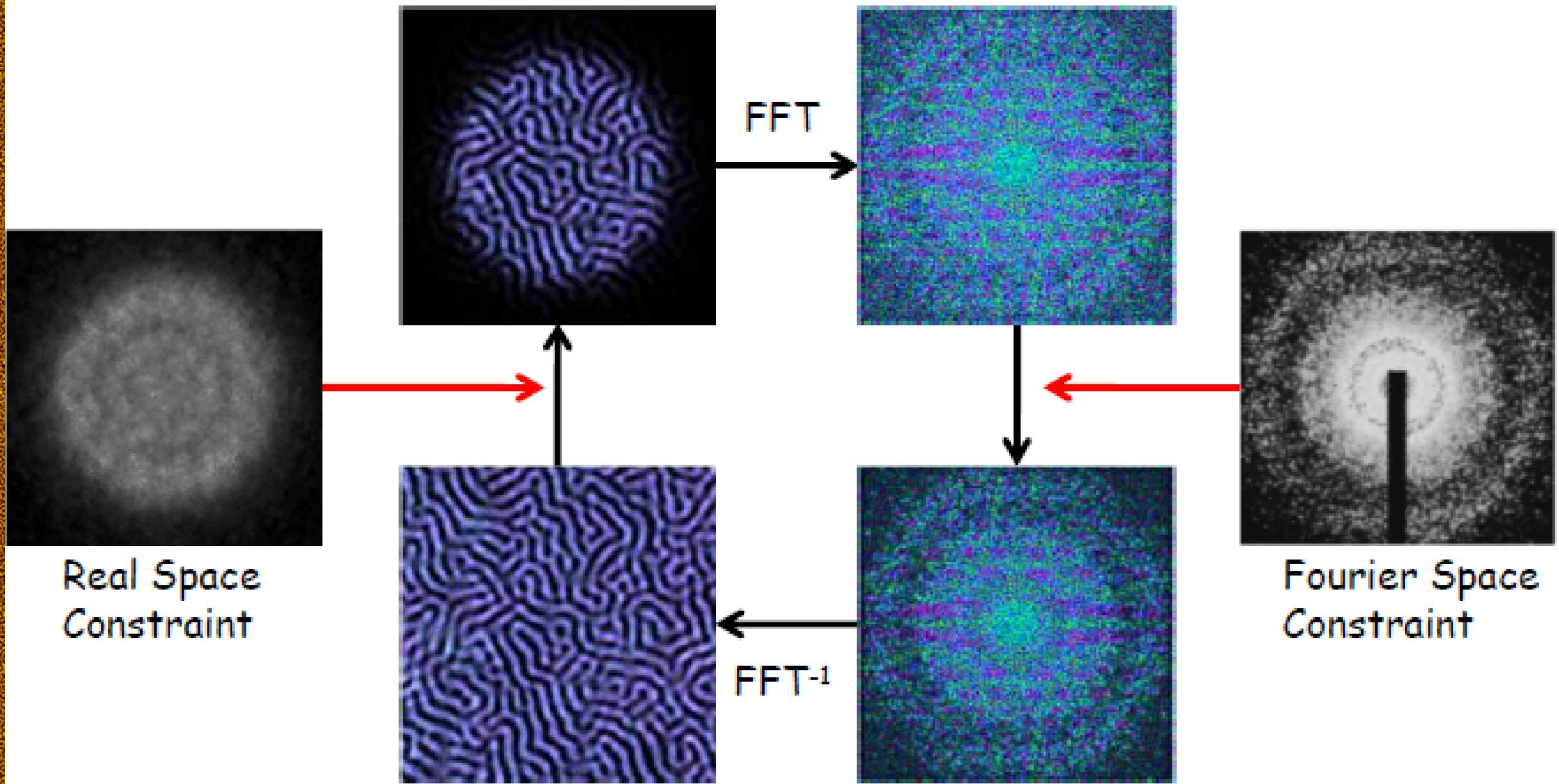


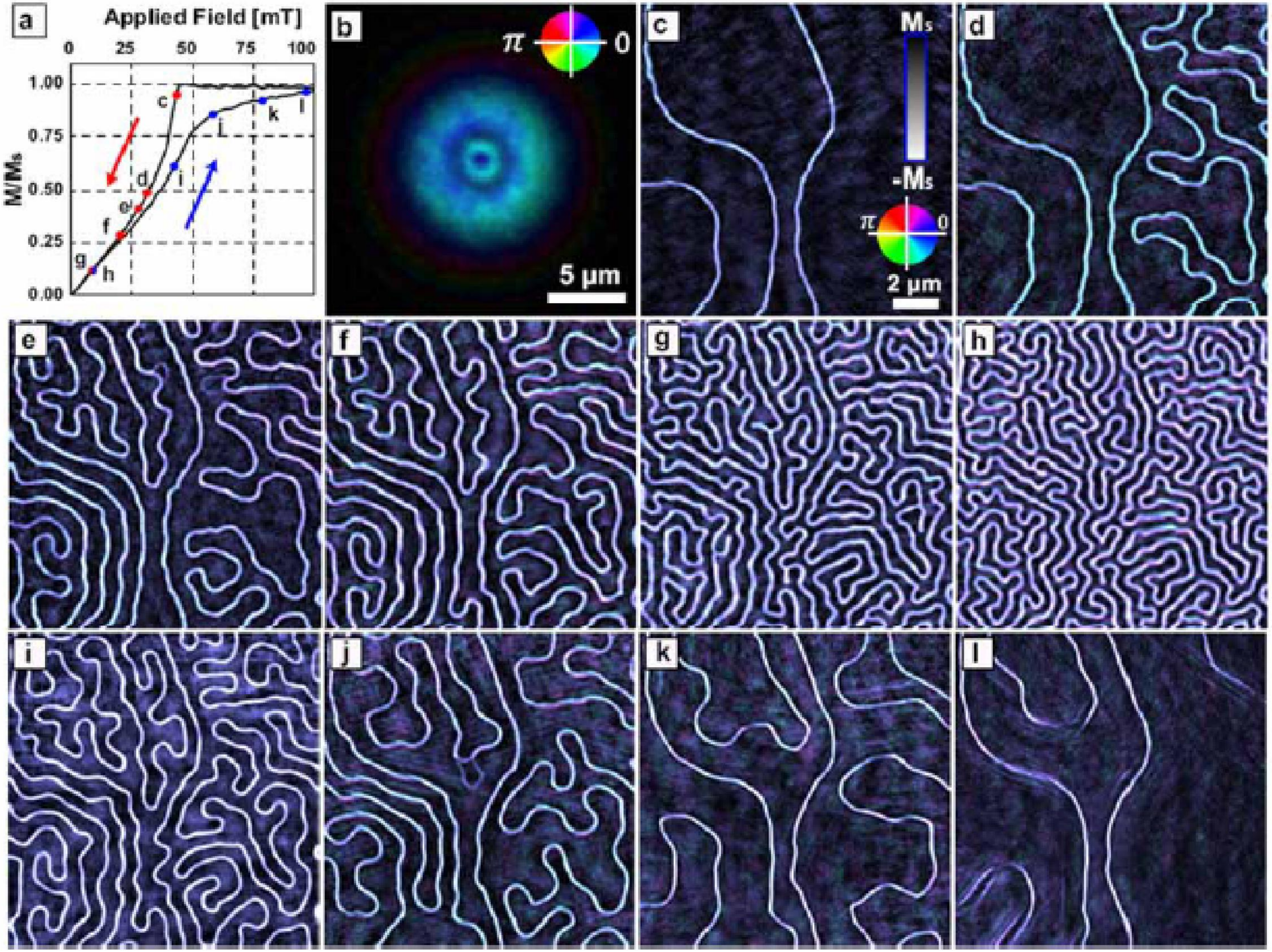
under preparation

Coherent Resonant Magnetic Scattering

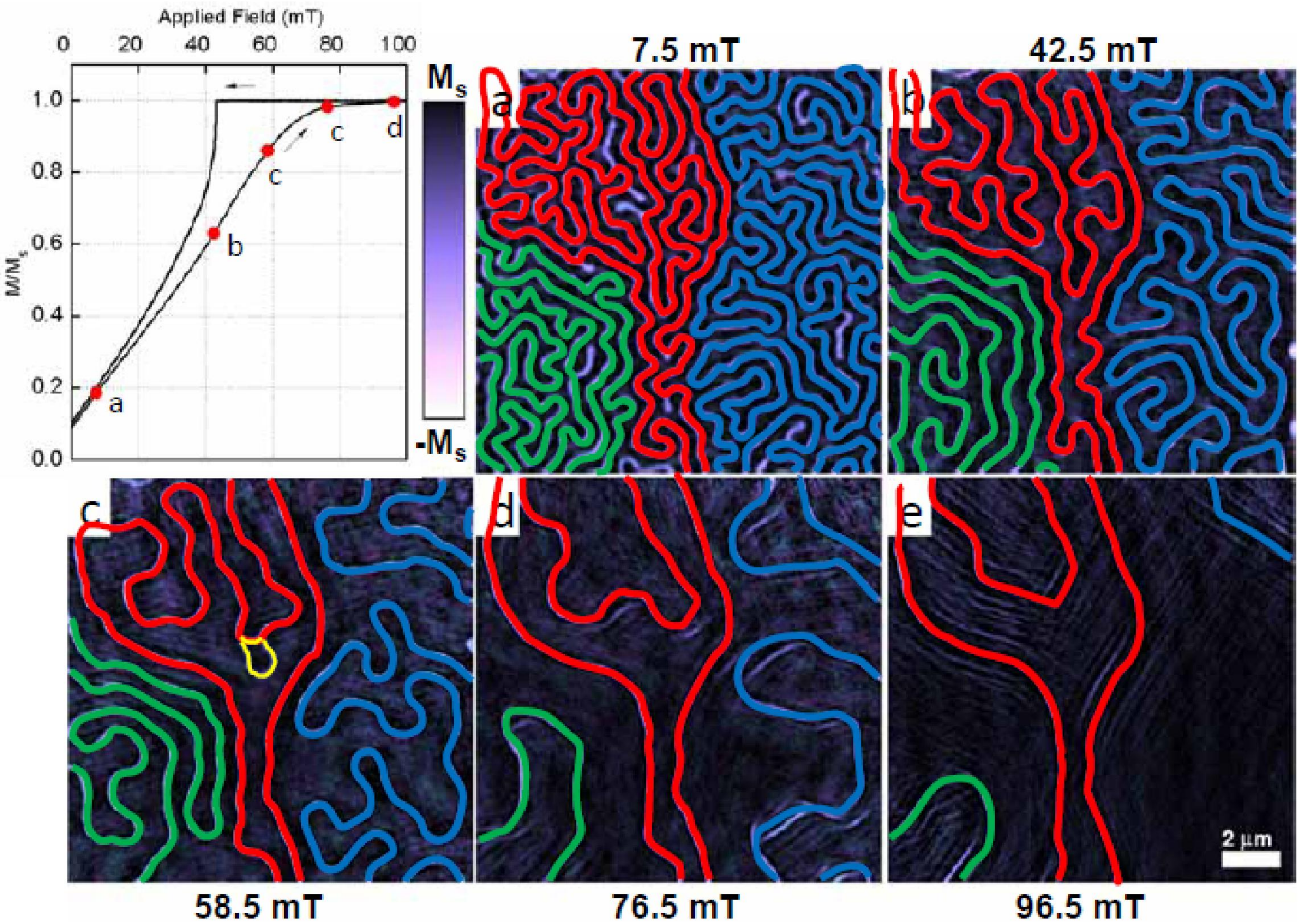


Phase Retrieval Algorithm





A. Tripathi, J. Mohanty *et al*. Proc Natl Acad Sci USA 108(33), 13393-13398 (2011)



Applied Field (mT)
0
20
40
60
80
100
1.0
0.8
0.6
0.4
0.2
0.0
M/M$_s$
a
b
c
c
d
M$_s$
-M$_s$
7.5 mT
42.5 mT
58.5 mT
76.5 mT
96.5 mT
a
b
c
d
e
2 μm

ScienceDaily®
Your source for the latest research news

Science News

Like Superman's X-Ray Vision, New Microscope Reveals Nanoscale Details

ScienceDaily (Aug. 8, 2011) — Physicists at UC San Diego have developed a new kind of X-ray microscope that can penetrate deep within materials like Superman's fabled X-ray vision and see minute details at the scale of a single nanometer, or one billionth of a meter.

Magnetic domains appear like the repeating swirls of fingerprint ridges. As the spaces between the domains get smaller, computer engineers can store more data. (Credit: UC San Diego)

See Also:

Matter & Energy
- Nanotechnology
- Physics

But that's not all. What's unusual about this new, nanoscale, X-ray microscope is that the images are not produced by a lens, but by means of a powerful computer program.

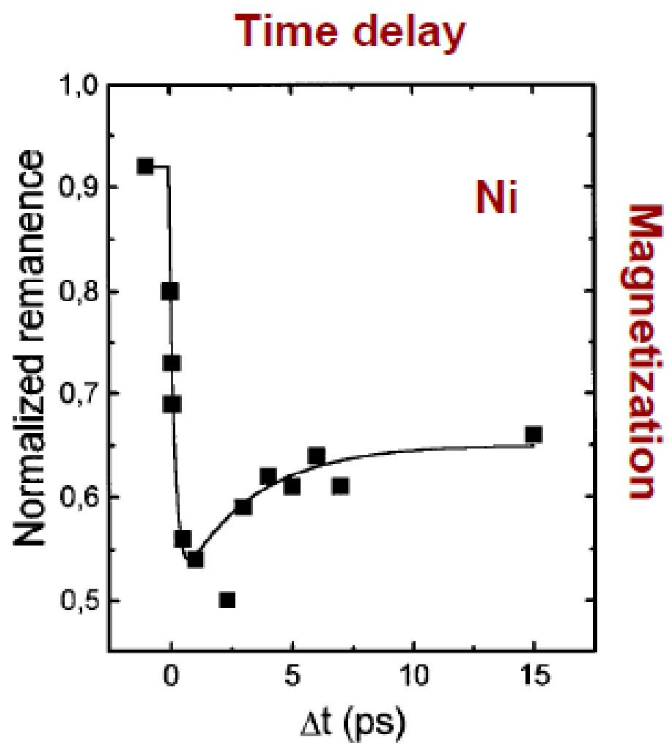
Better Than Superman X-Ray Microscope Enables Nanovision

Fox Video, Fox News, UCSD News, Popular Science, MSNBC, MRS, Photonics, Sciencedaily, Physorg, , Nanotechnow, Livejournal, Innovation Report, Physnews, Labspaces, Eurekaalert, Esciencenews, Scienceblog, UPI, Rdmag, Firstscience, Technews

India Coverage:

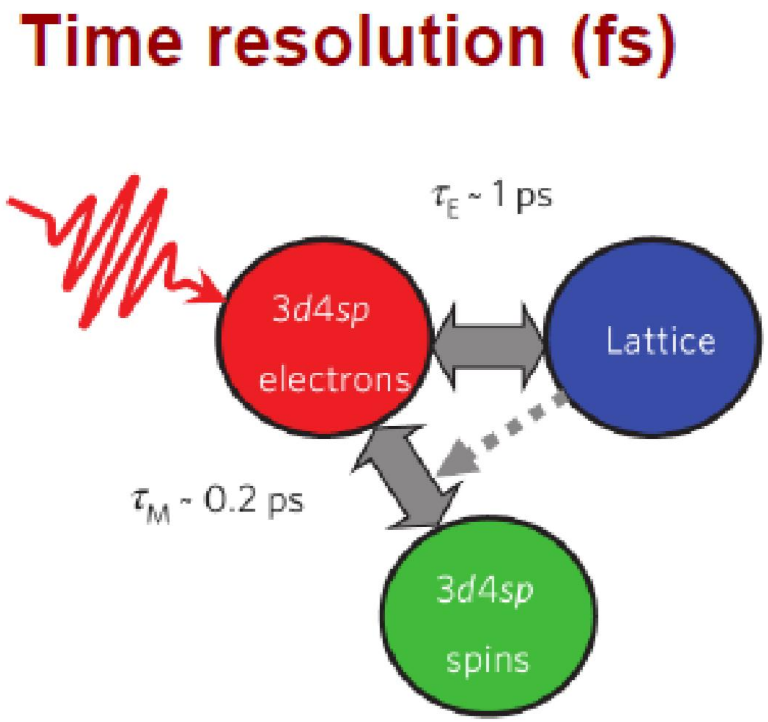
Yahoo News, TheHindu, Zee Tech News, Andhranews, Dailyindia

Ultrafast Demagnetization



Time-resolved MOKE

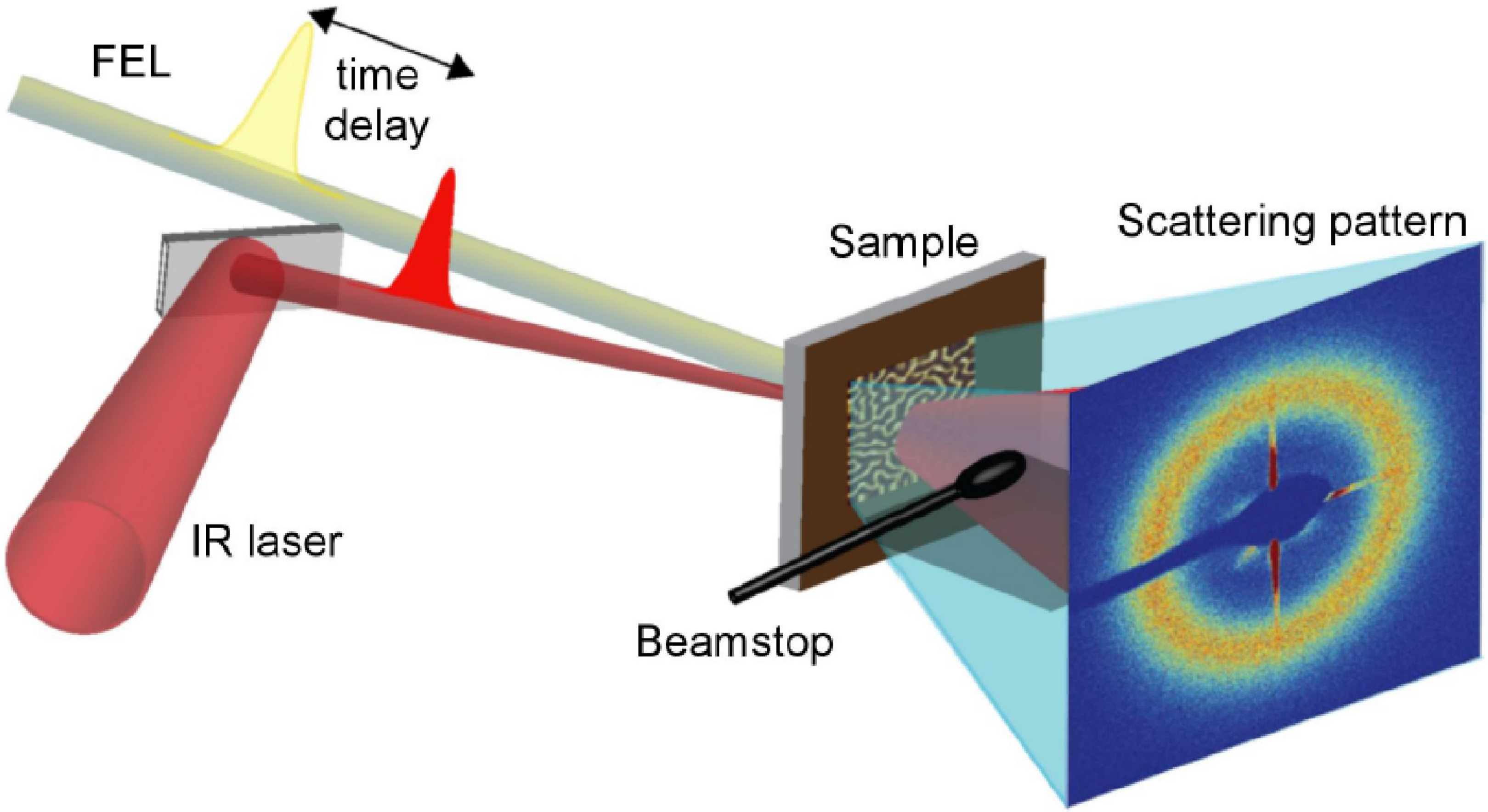
Ni: 120 fs

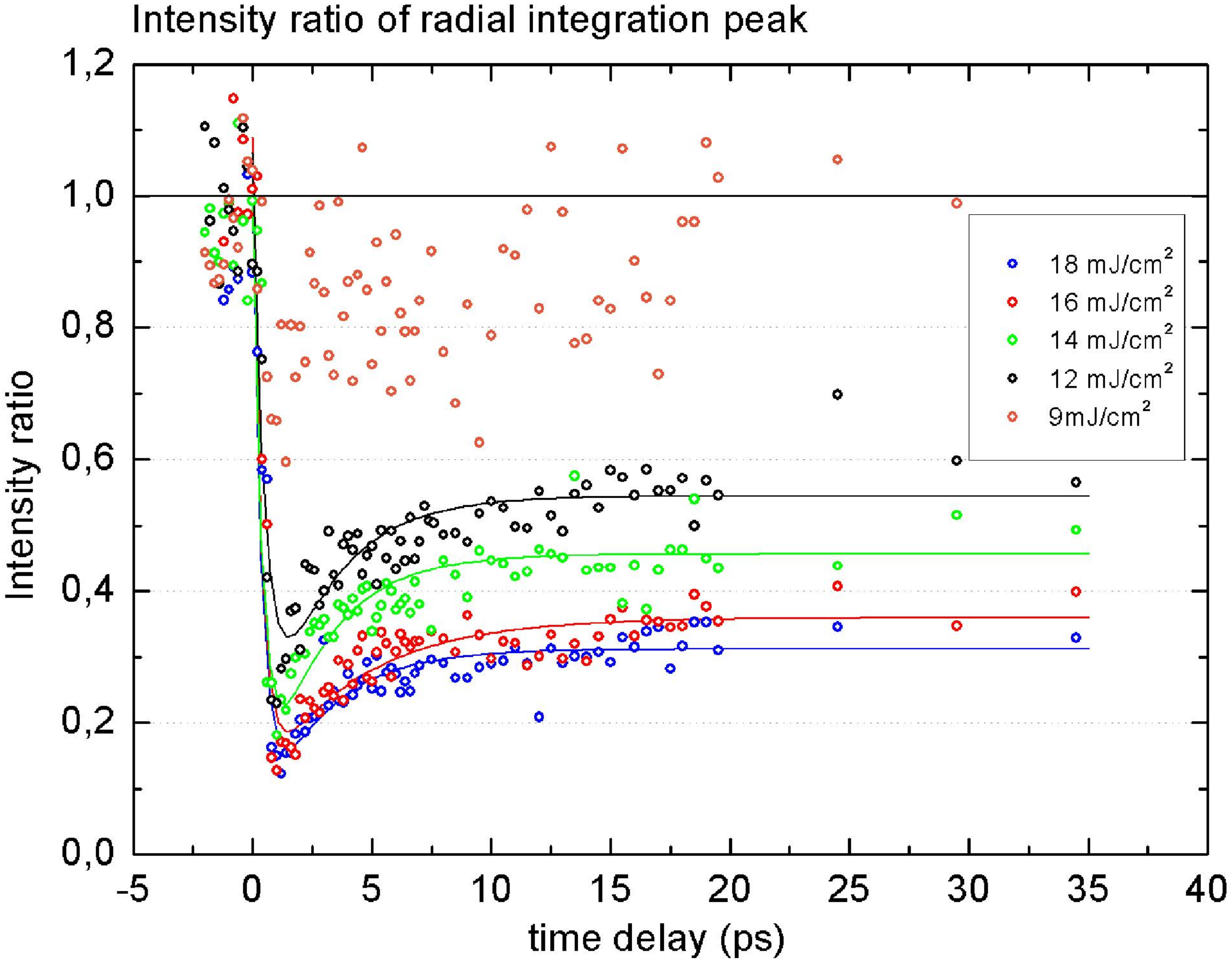


three-temperature model

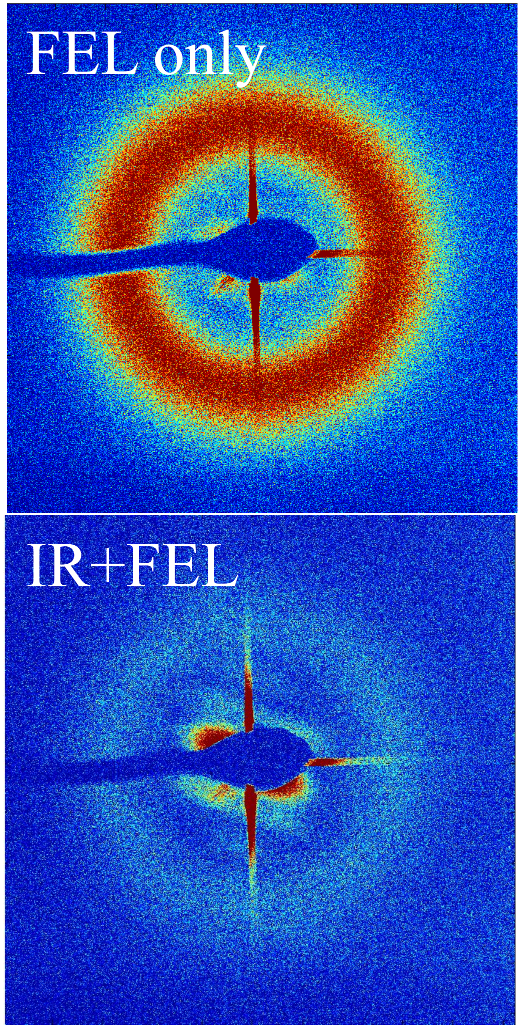
E. Beaurepaire et al., PRL **76**, 4250 (1996)

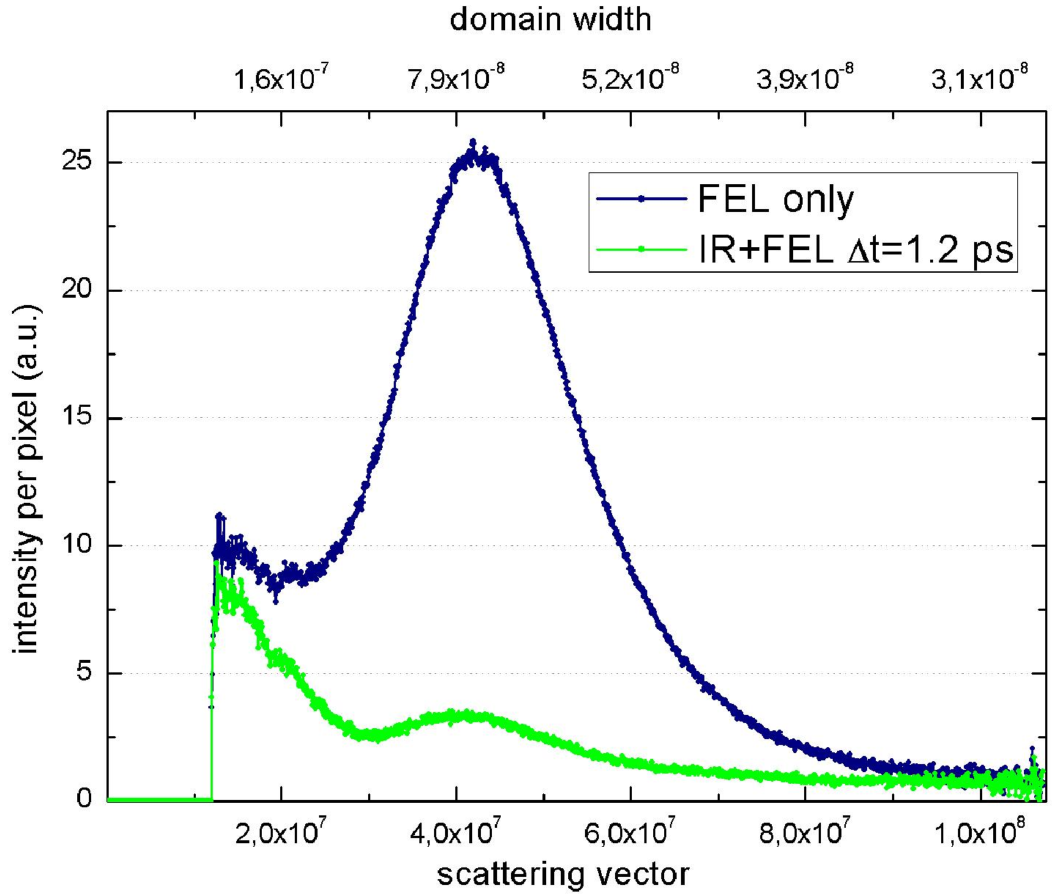
Ultrafast Demagnetization





- reproduce optical results
- characteristic demagnetization time constant below 1 ps

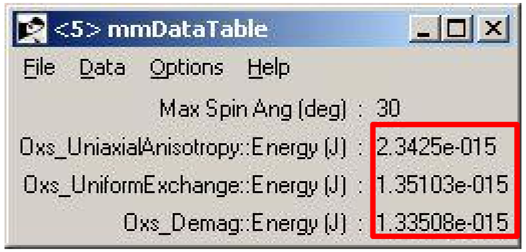




- Change of the domain size in only some 100 fs over a large area
- Movement of domain walls is much slower!

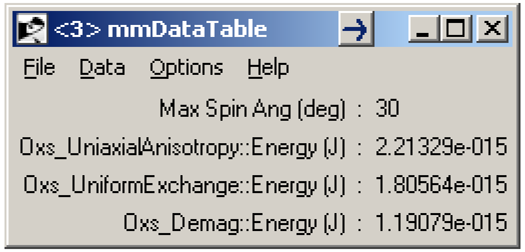
Micromagnetic Simulation

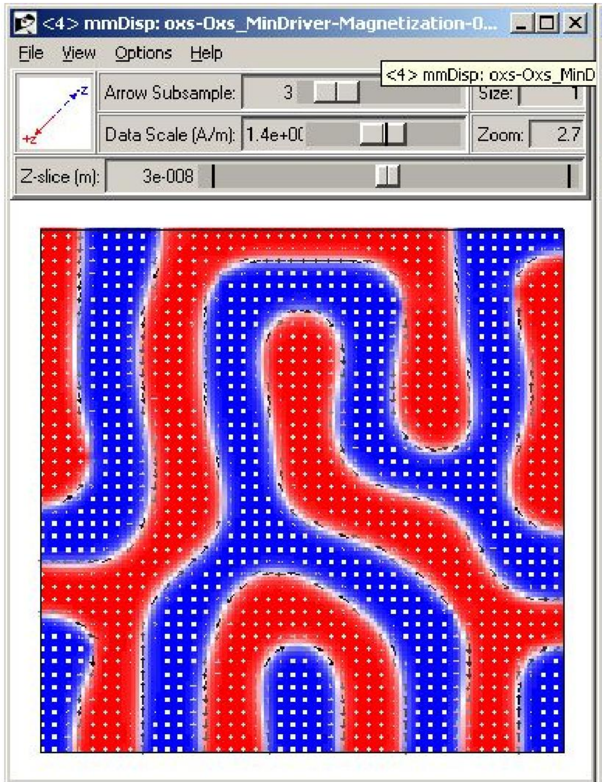
Case 1: Wiggly domains



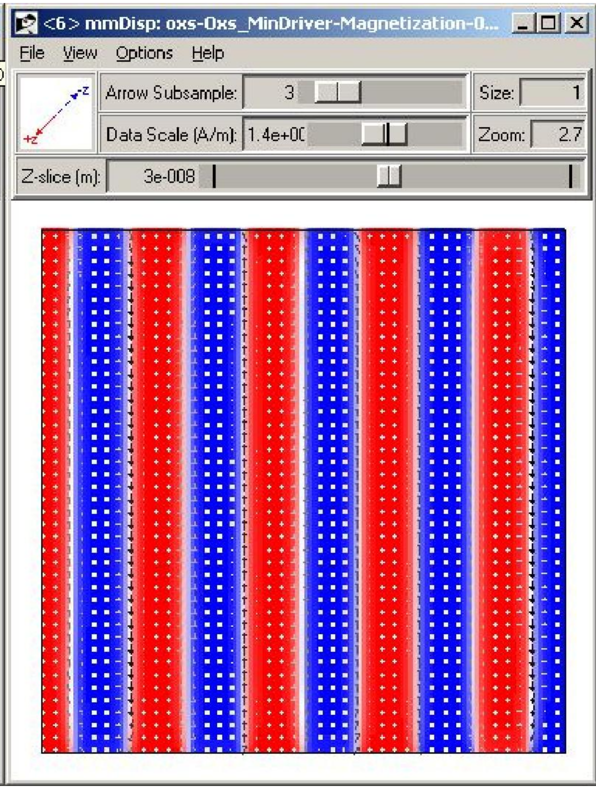
0.5x0.5mu^2

2.27e-15
1.49e-15
1.22e-15

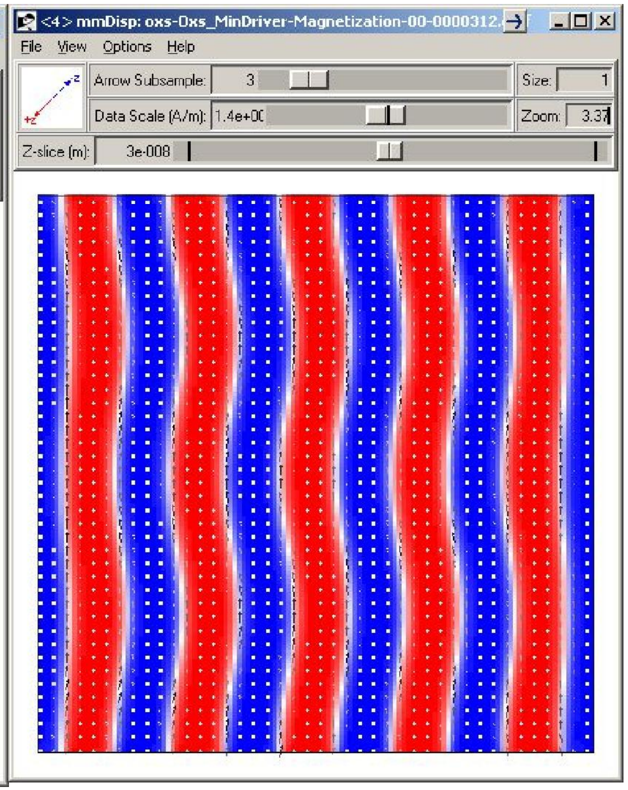




random



stripes

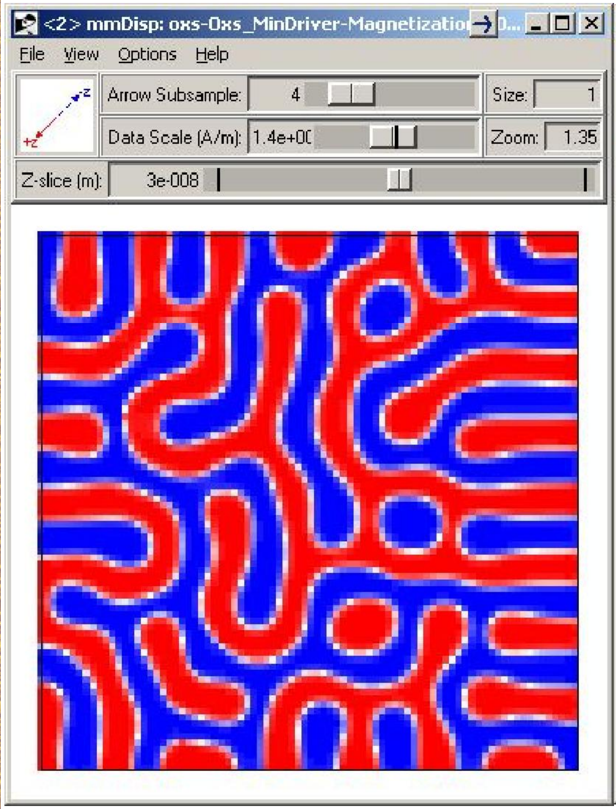


wiggly

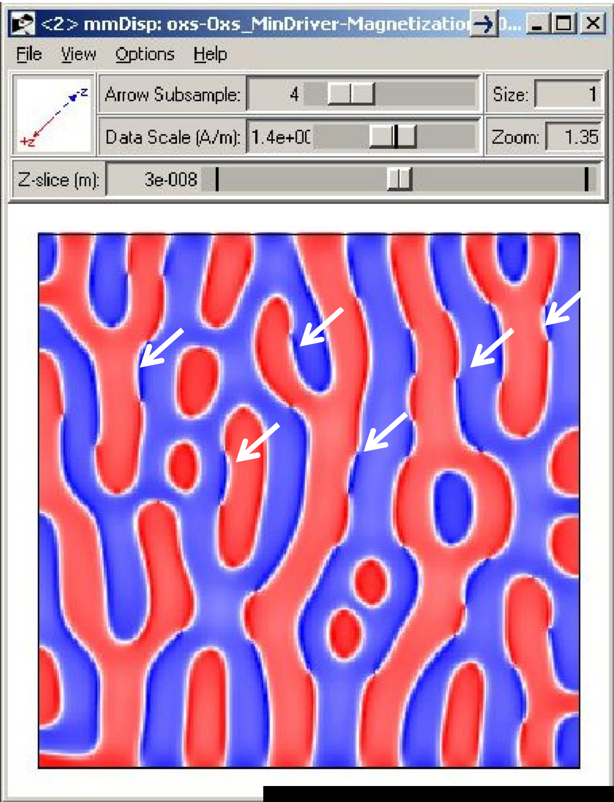
Micromagnetic Simulation

Case 2: tilted easy axis (weak anisotropy)

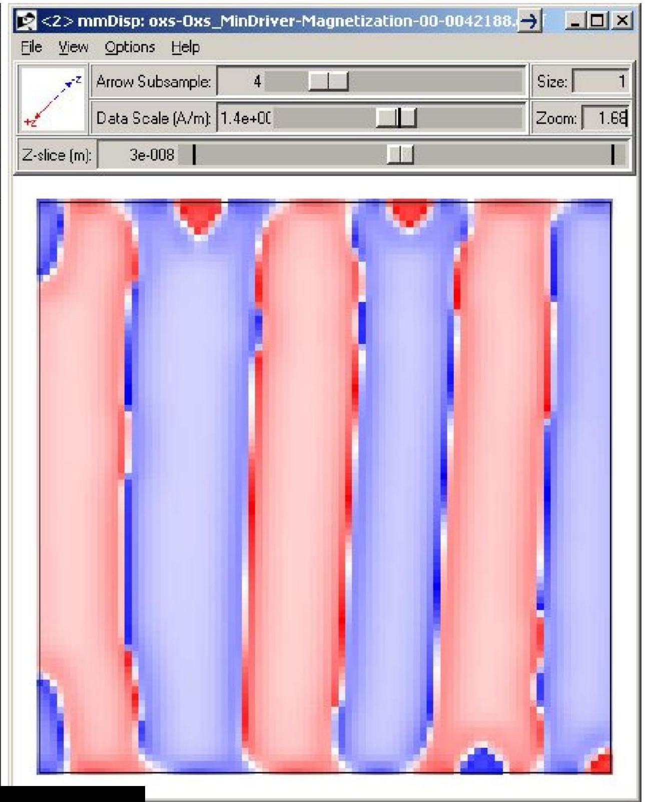
(0 0 1)



(0 0.5 1)



(0 1 1)



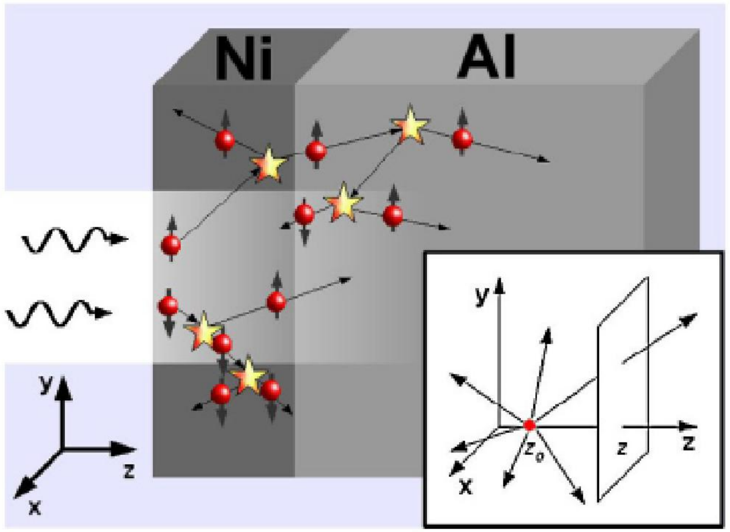
- wider domain
- less contrast

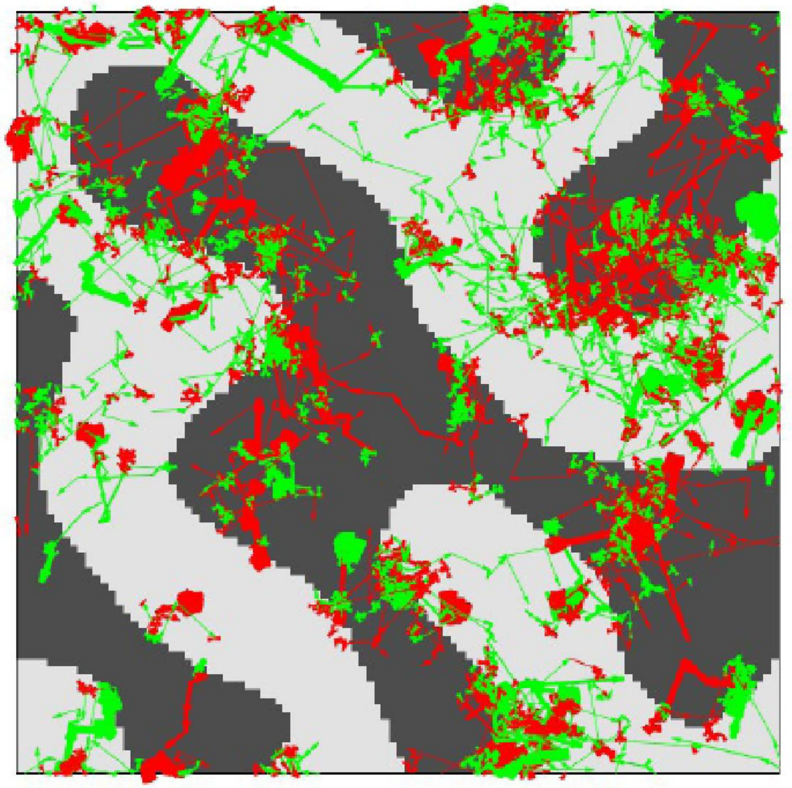
Our stand point

PRL 105, 027203 (2010) PHYSICAL REVIEW LETTERS week ending 9 JULY 2010

Superdiffusive Spin Transport as a Mechanism of Ultrafast Demagnetization

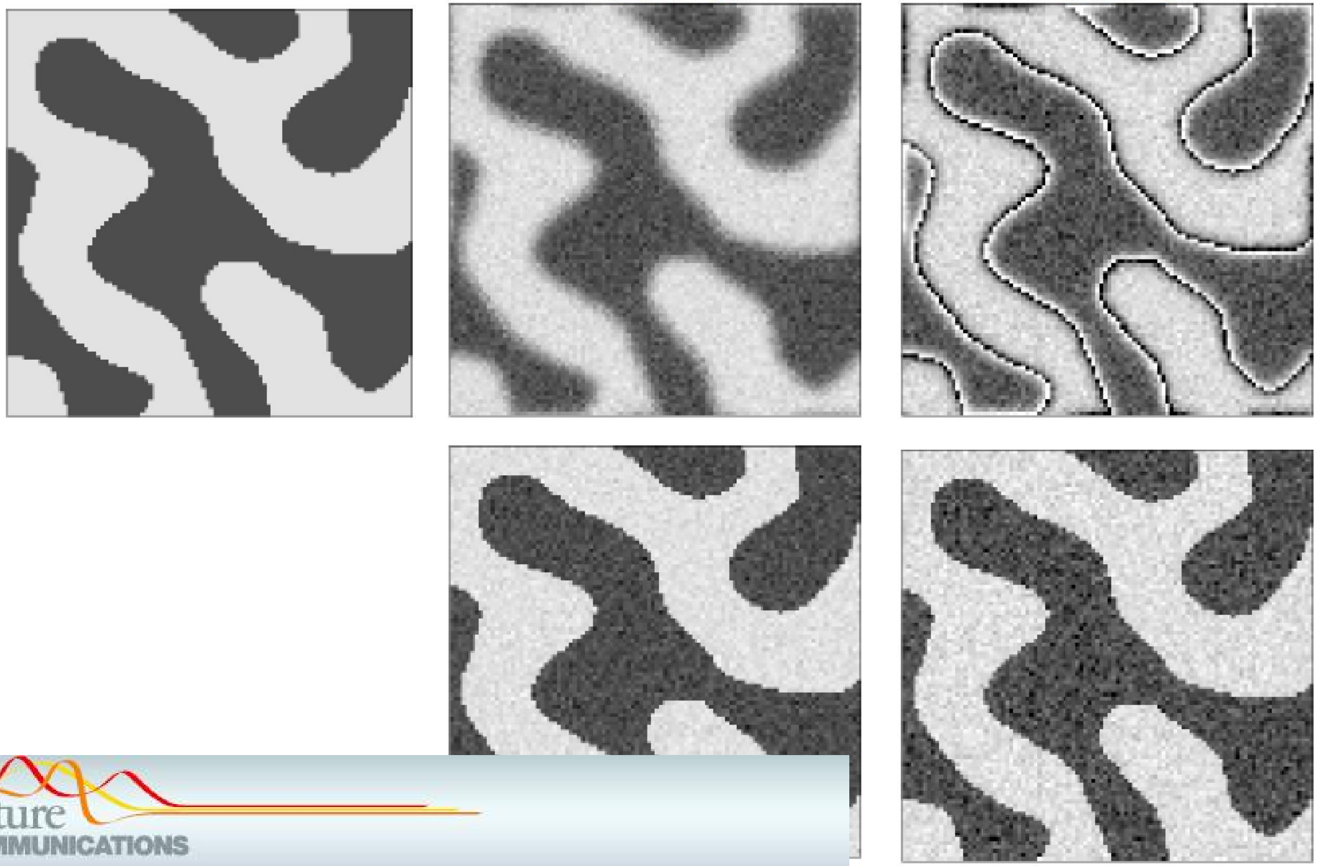
M. Battiato,* K. Carva,† and P. M. Oppeneer
Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden
(Received 31 March 2010; published 9 July 2010)





Our stand point

Monte-Carlo Simulation



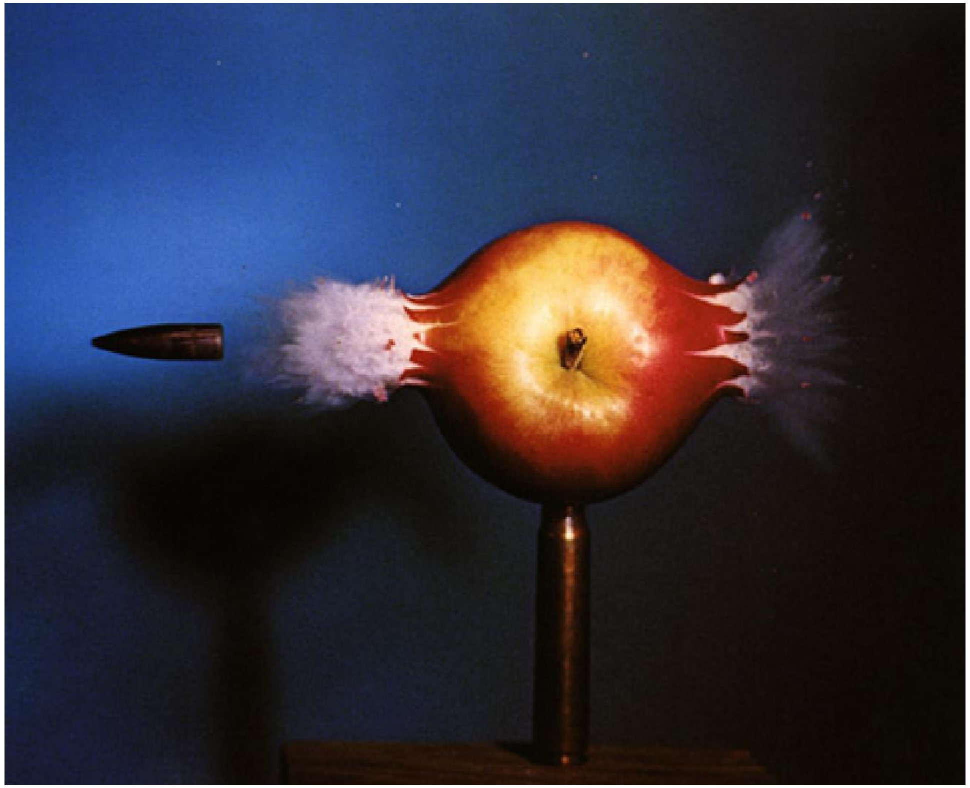
nature COMMUNICATIONS

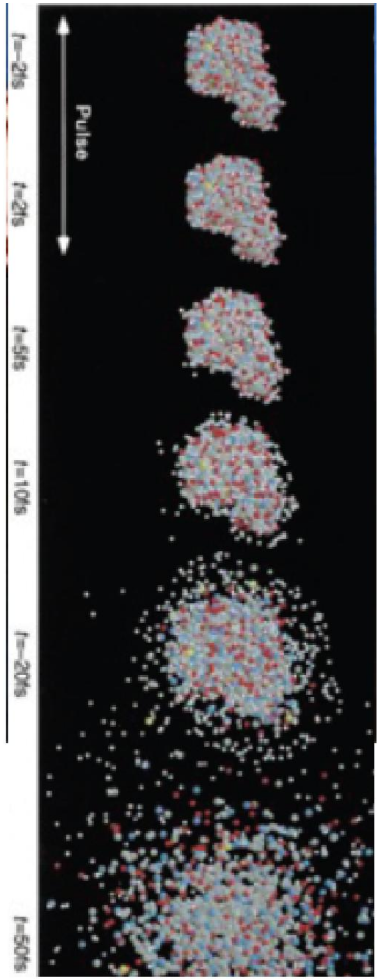
ARTICLE

Received 18 Apr 2012 | Accepted 3 Sep 2012 | Published 2 Oct 2012 DOI: 10.1038/ncomms2108

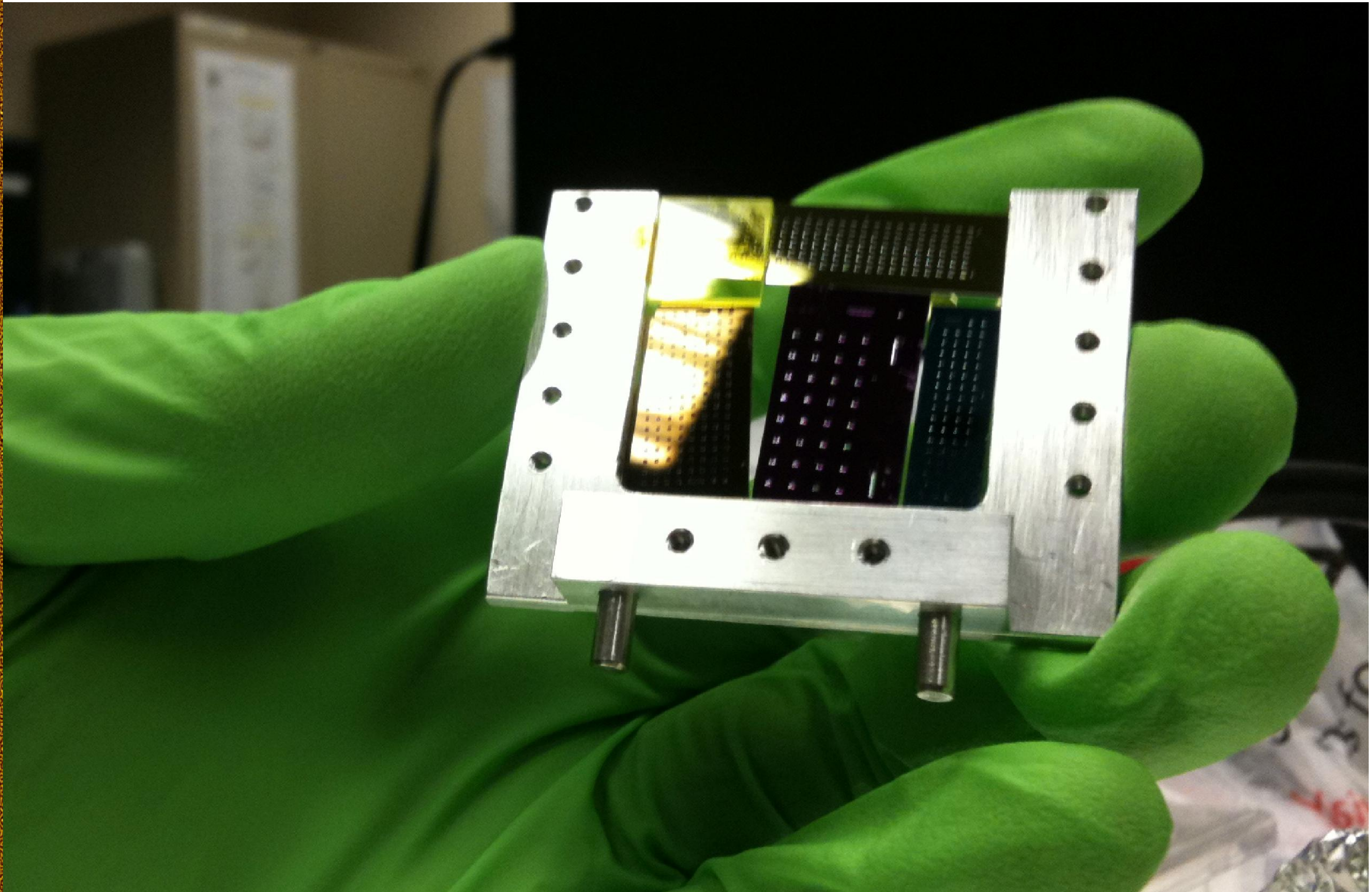
Ultrafast optical demagnetization manipulates nanoscale spin structure in domain walls

Single-shot Imaging

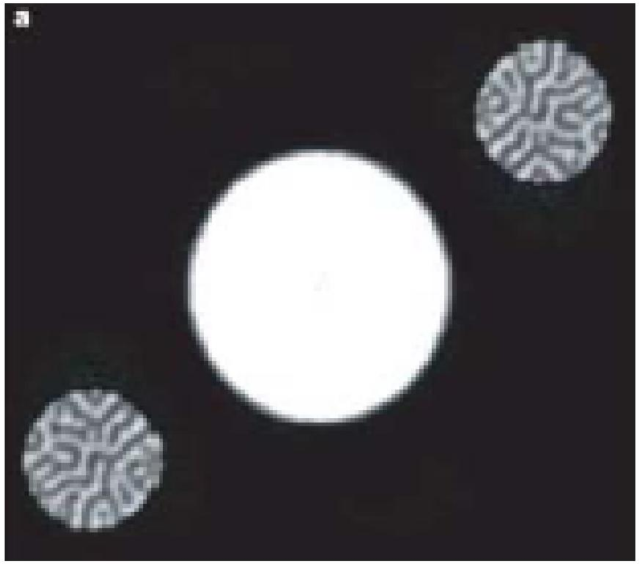


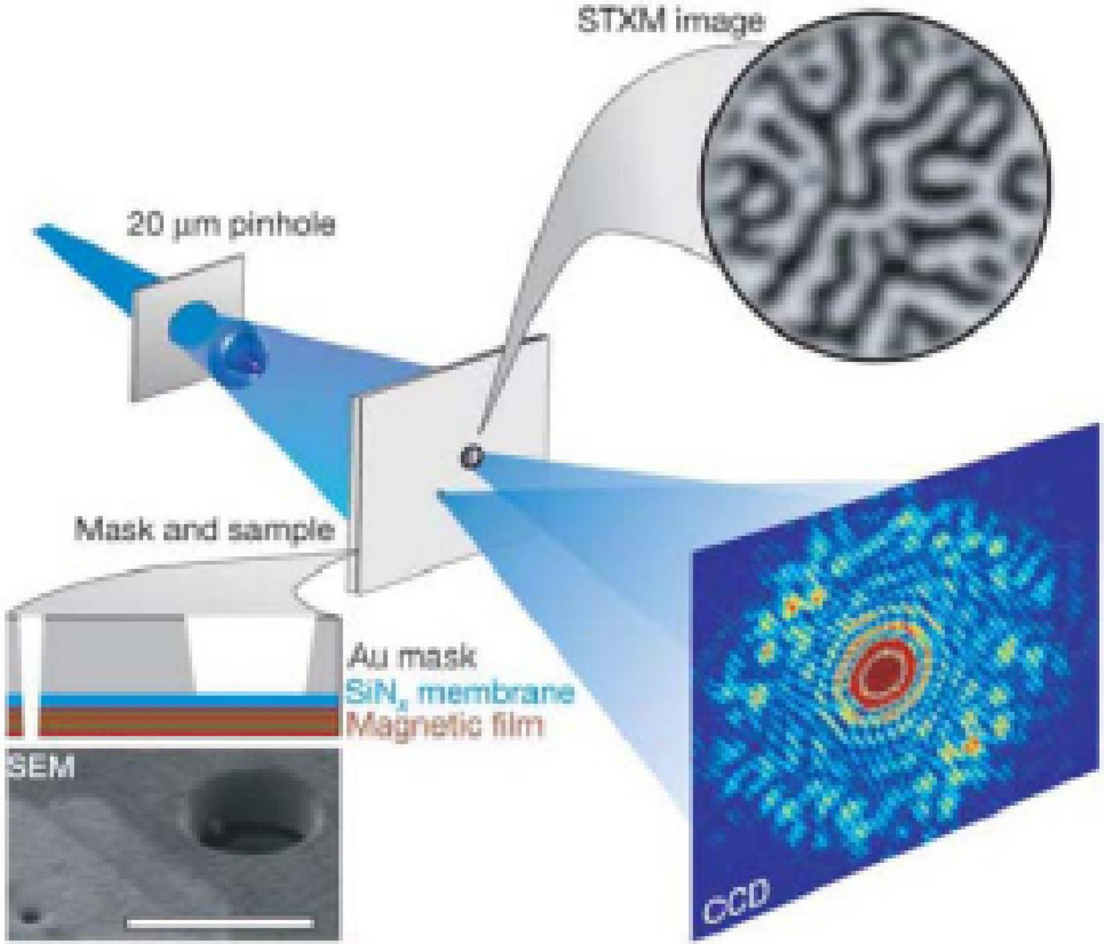


Single-shot Imaging



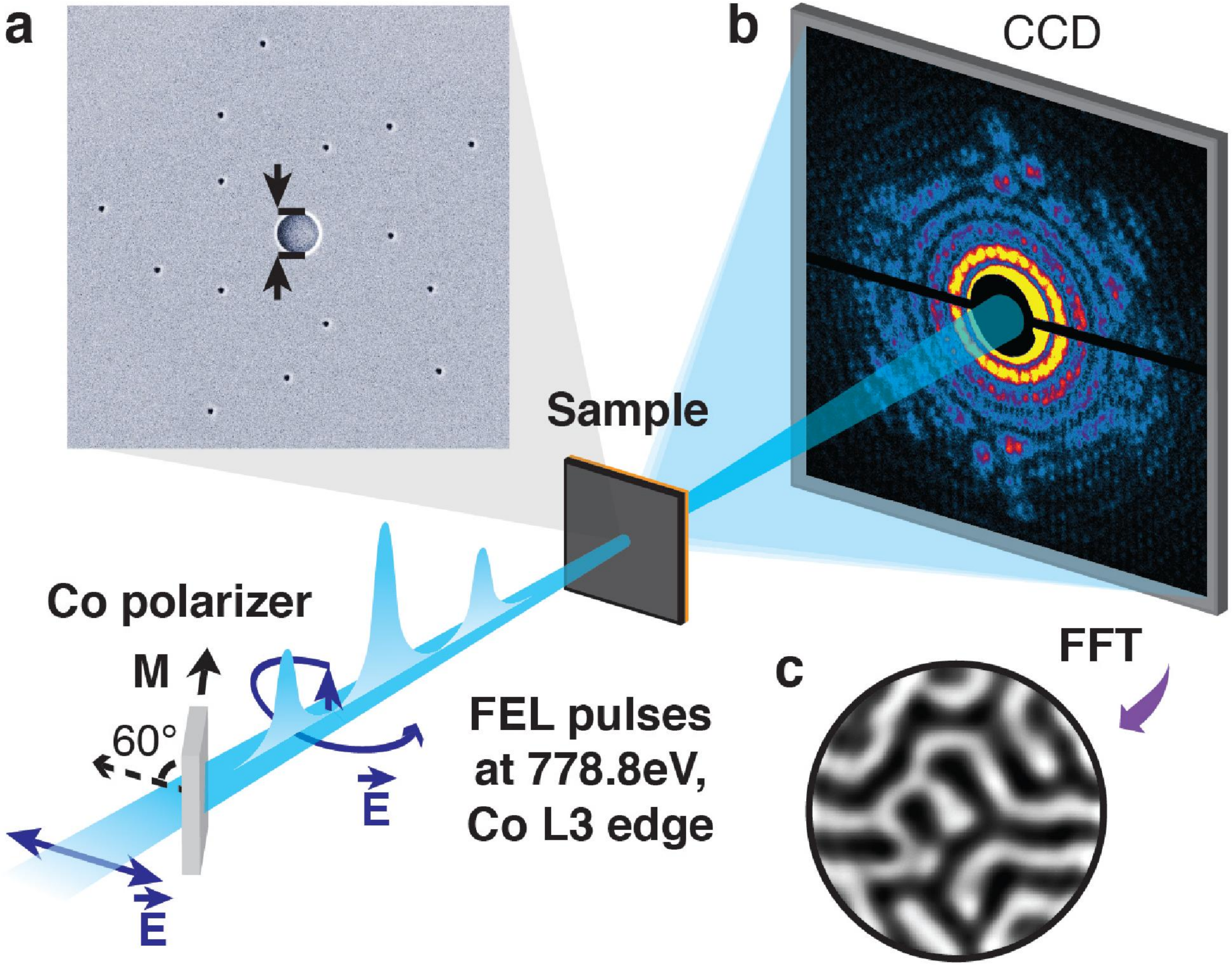
X-ray Holography

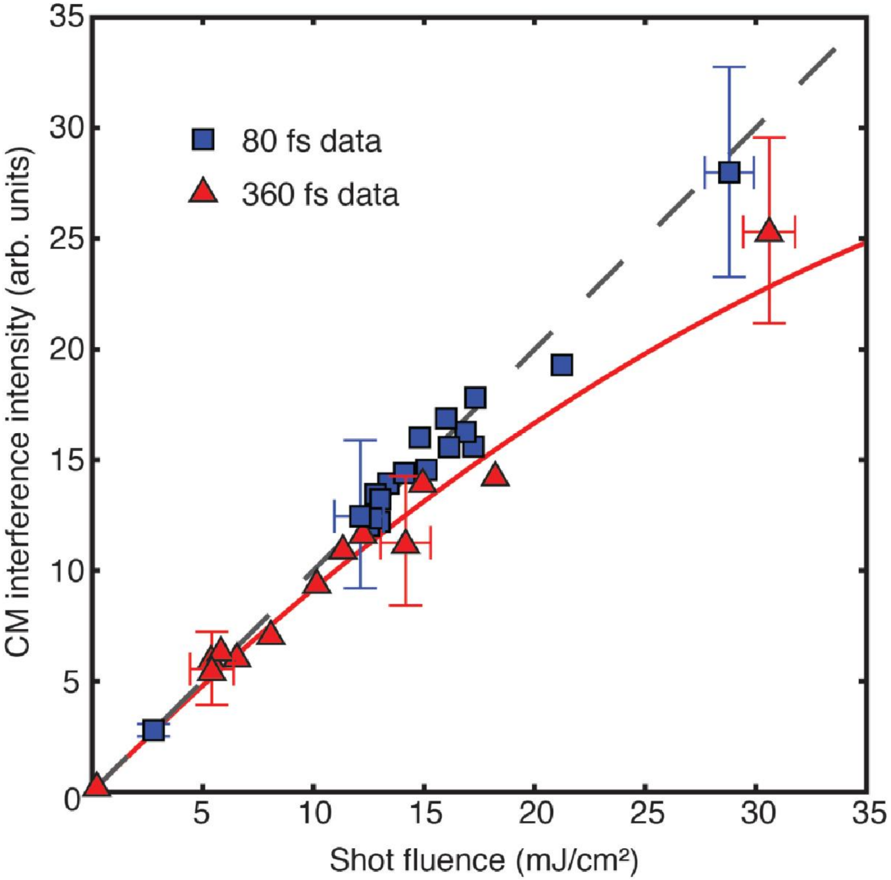


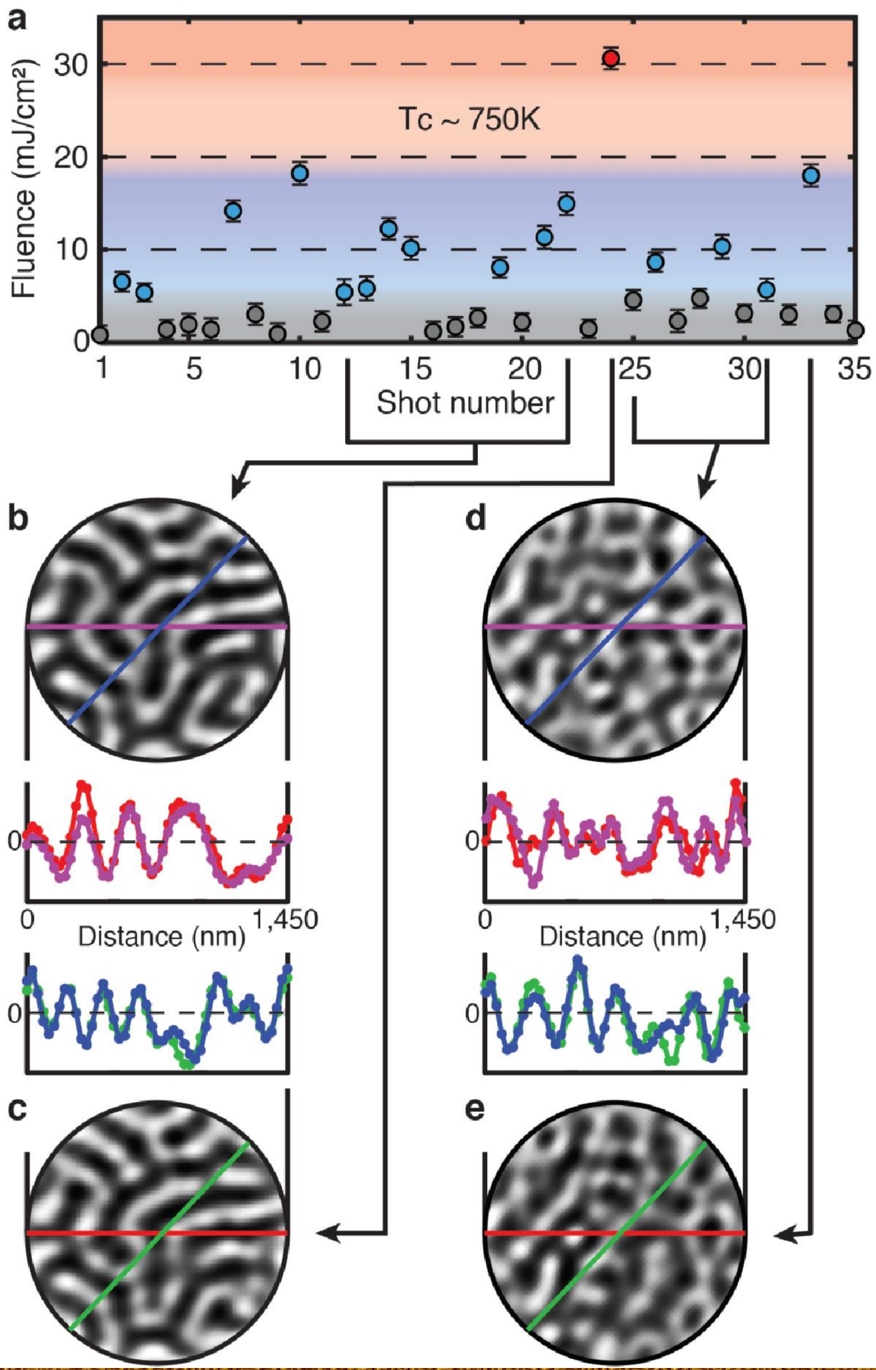


S. Eisebitt et al., Nature (2004)

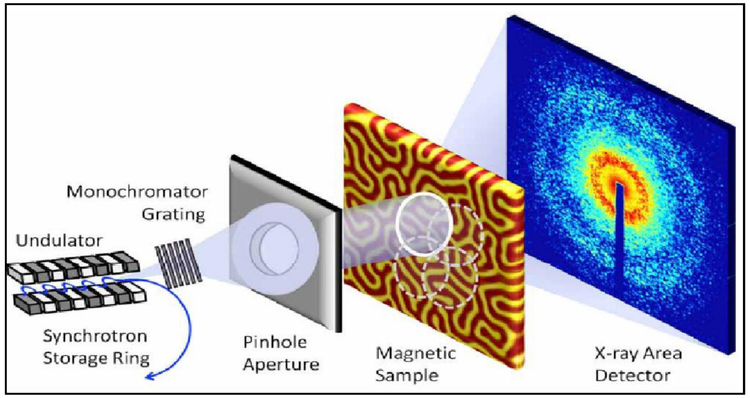
Single-shot imaging



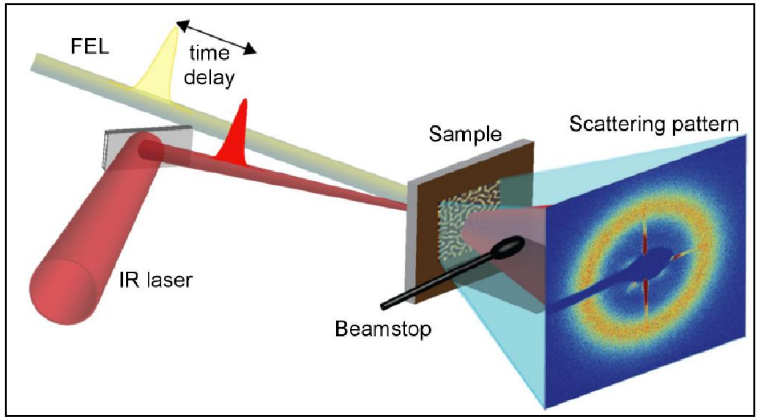




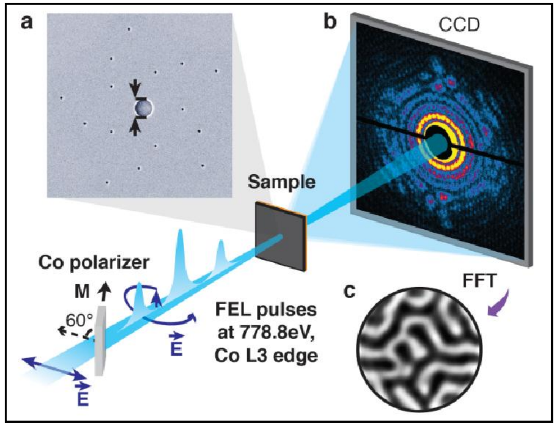
PRL 108, 267403 (2012)



- Nanoscale dynamics
- Lensless imaging



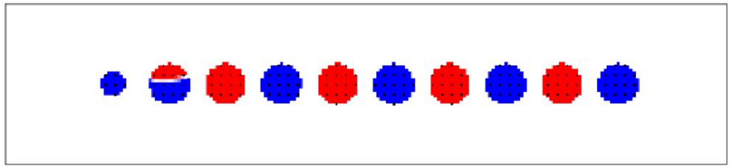
- Ultrafast Demagnetization



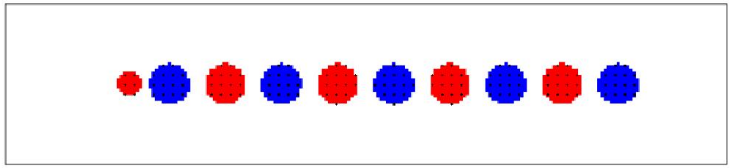
- Single-shot Imaging

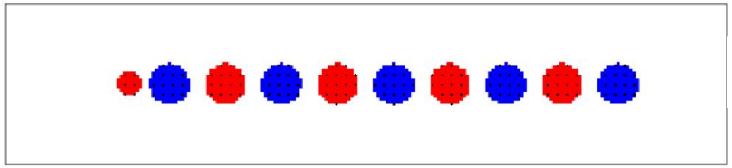
Quantum Dot Cellular Automata

30-30-50-20 (CoPt)

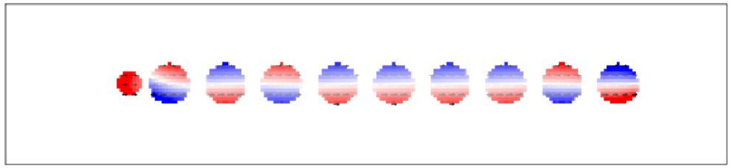


30-10-50-20

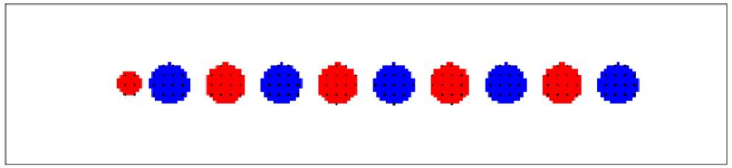




ground state

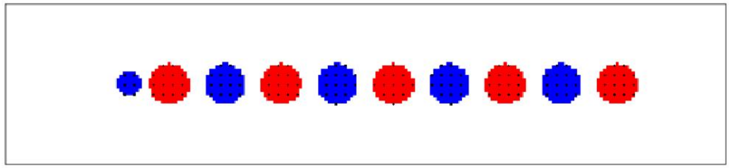


800mT



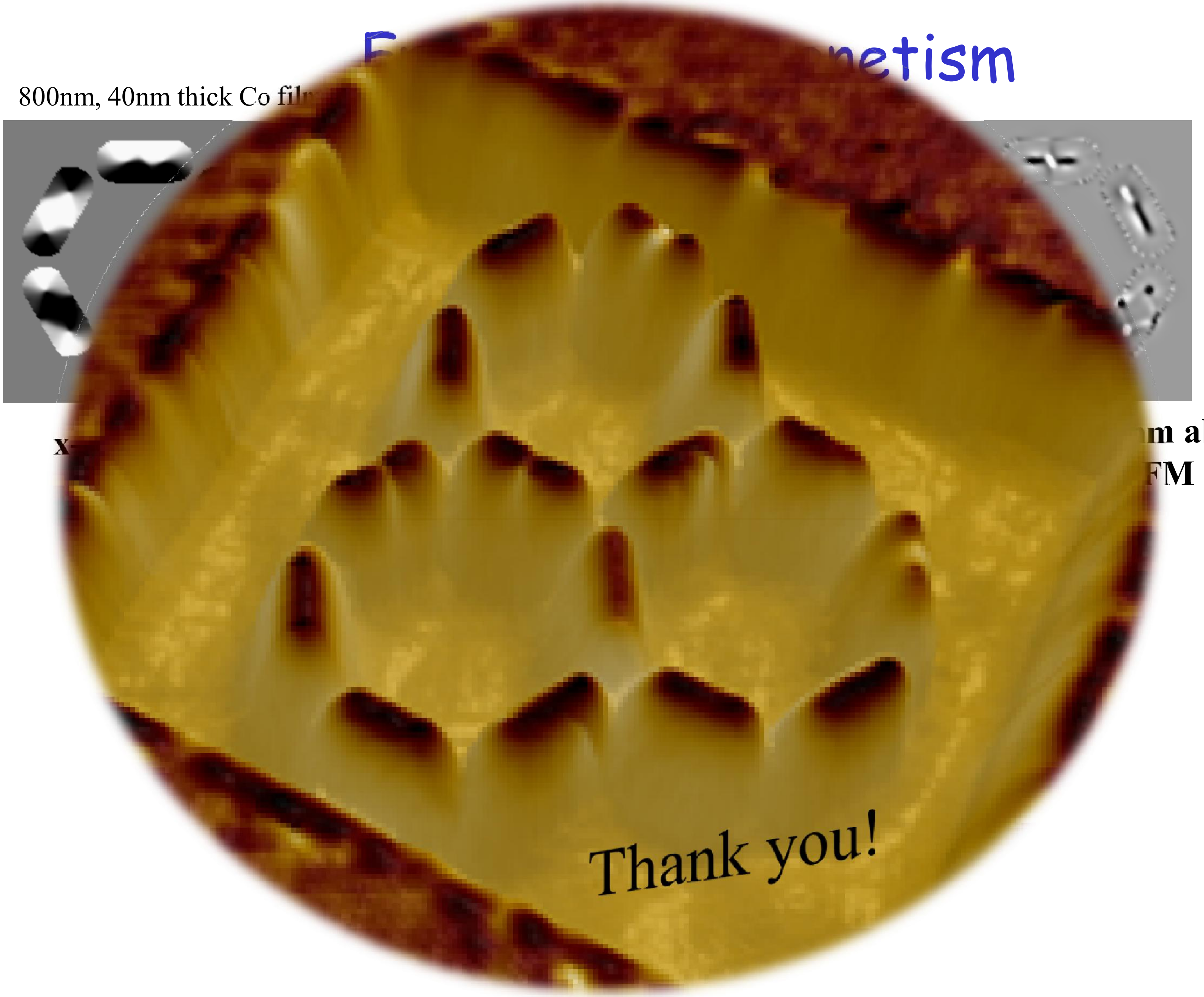
0mT

ground state, 1st dot flipped



F... ...netism

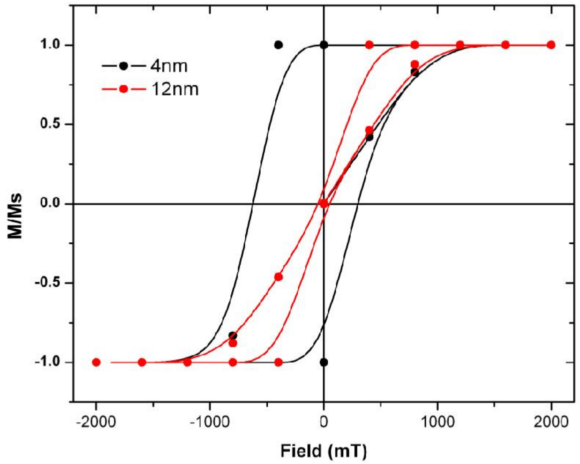
800nm, 40nm thick Co fil...

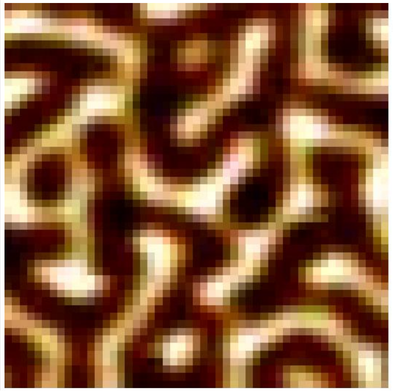


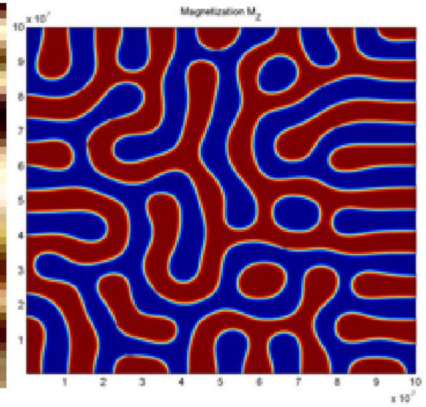
x...

...m above
...FM

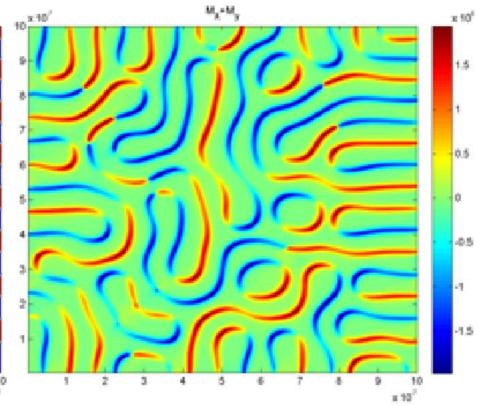
Micromagnetic Simulation



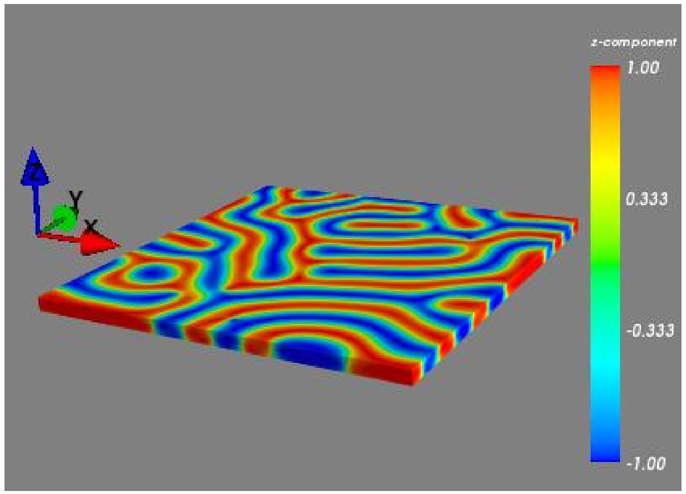




Domain



Domain wall



- Magnetic Hysteresis
- Magnetic domain in multilayers
- Field and temperature induced dynamics
- Magnetic dot lattice: role of size, defect, pinning sites