Magnetization processes inside domain walls

Olivier Fruchart
Institut Néel (CNRS-UJF-INPG)
Grenoble - France

http://neel.cnrs.fr

Magnetization reversal of vortices

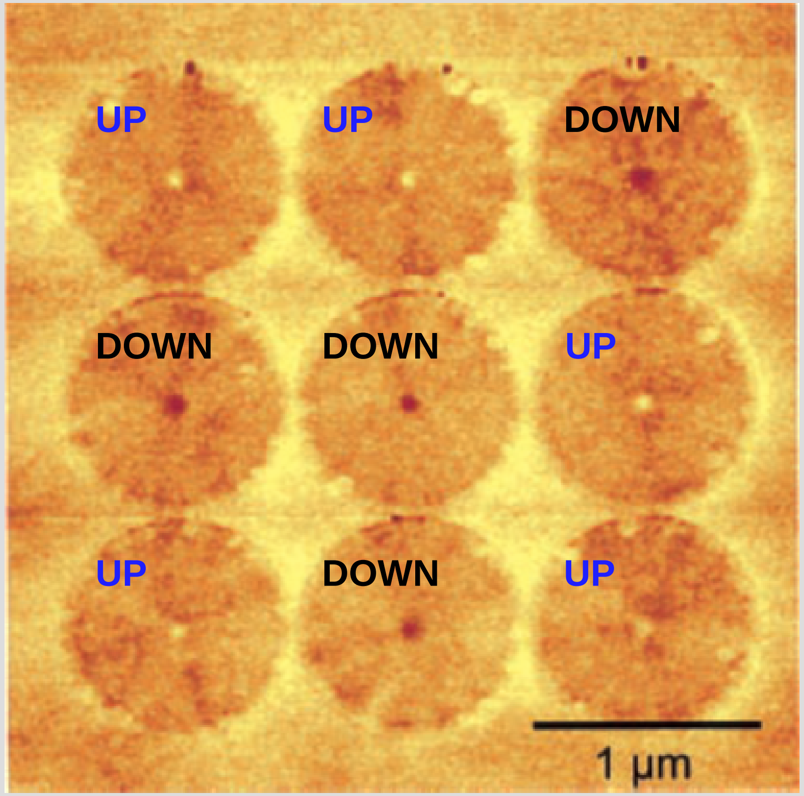


Fig. 2. MFM image of an array of permalloy dots 1 µm in diameter and 50 nm thick.

The central magnetic vortex can be magnetized up or down using a perpendicular field

T. Shinjo et al., Science 289, 930 (2000)
T. Okuno et al., JMMM240, 1 (2002)

See also

A. Wachowiak et al., Science 298, 577 (2002)

A. Thiaville et al., Phys. Rev. B 67, 094410 (2003)

B. Van Waeyenberg et al., Nature 444, 461 (2007)

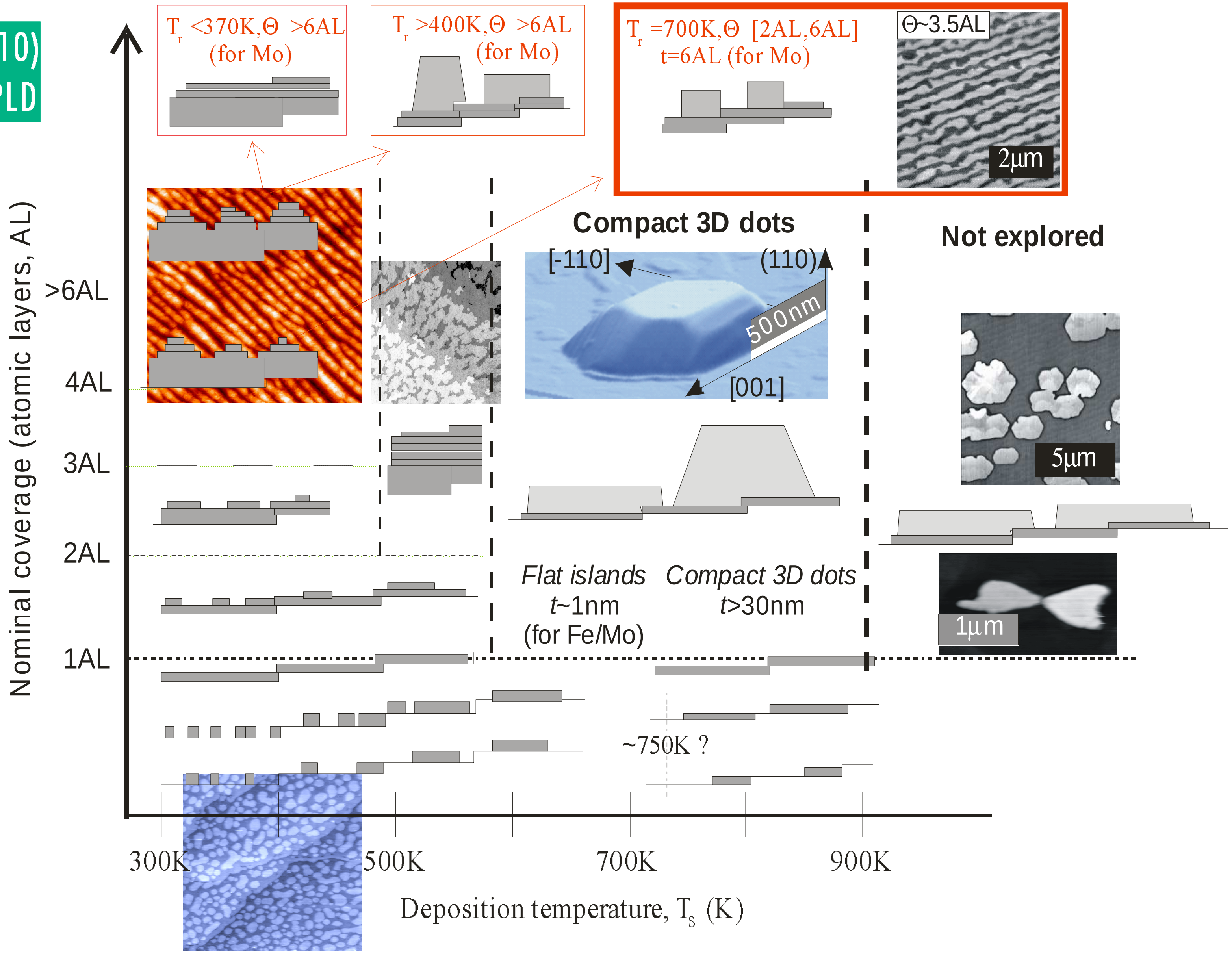
R. Hertel et al., Phys. Rev. Lett. 98, 117201 (2007)

K. Yamada et al., Nat. Mater. 6 (2007)

Motivations

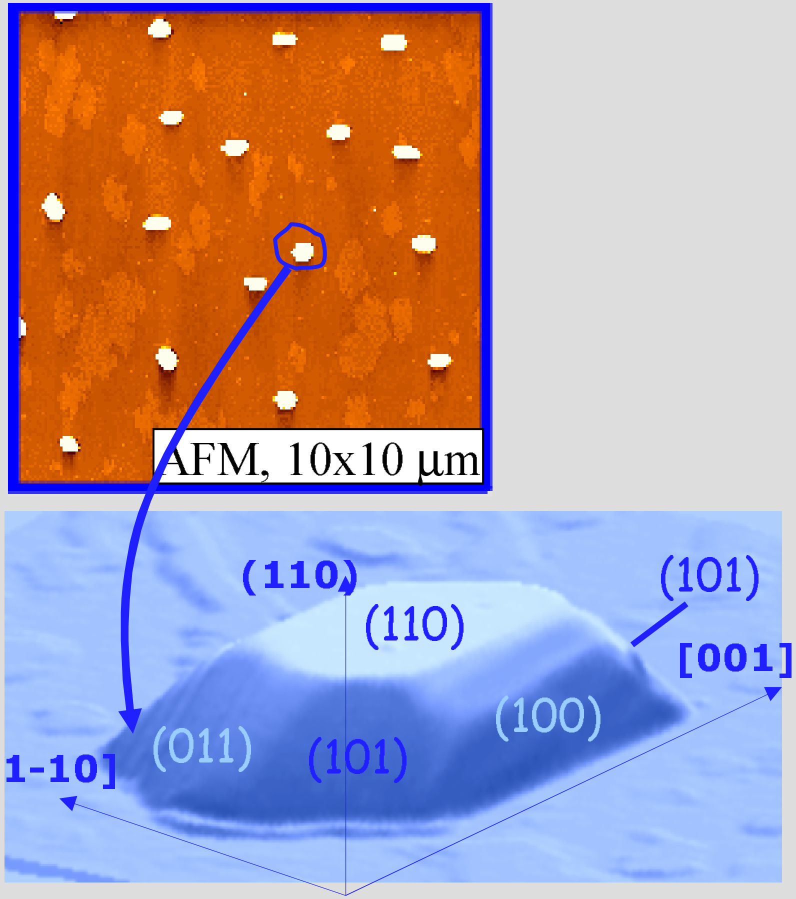
- Fundamental: go beyond magnetization reversal of domains
- 'Applied': store 2 bits of information in one single dot

Overview of Fe(110) growth by PLD



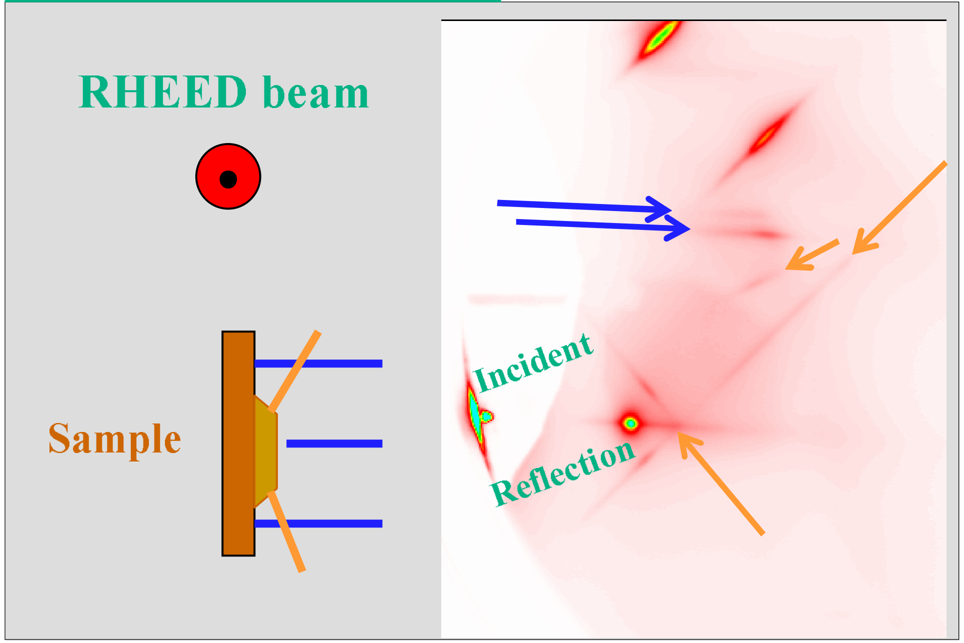
O. Fruchart et al., J. Phys.: Condens. Matter 19, 053001, Topical Review (2007).

Fe/Mo(110) @ 450℃

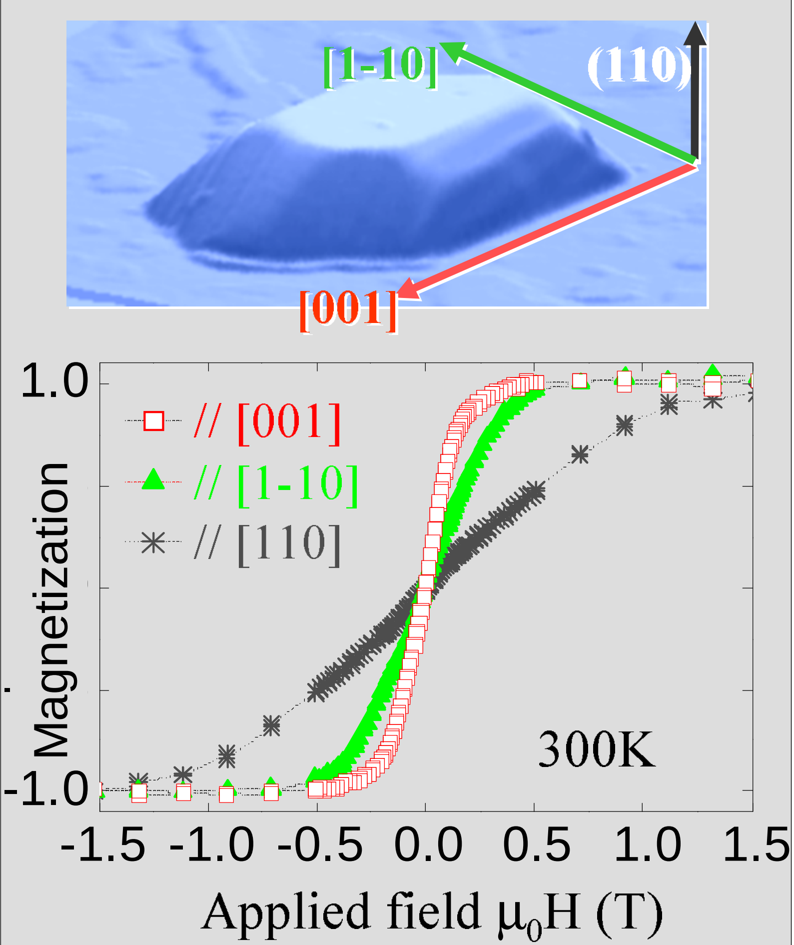


P.-O. Jubert *et al.*, JMMM 226, 1842 (2001)
P.-O. Jubert *et al.*, PRB64, 115419 (2002)

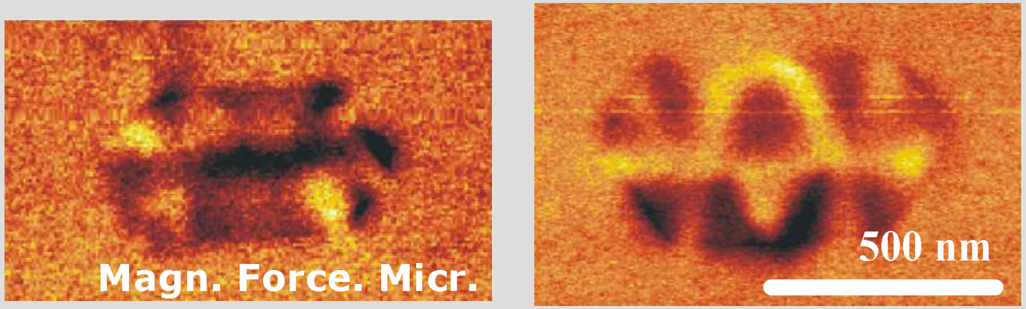
Atomically flat facets



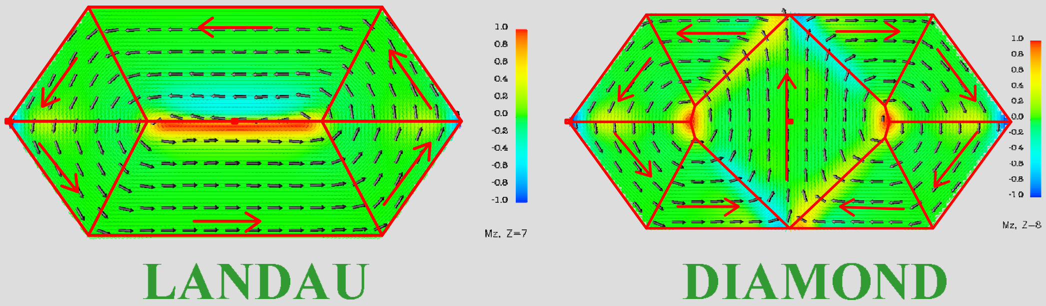
Model system
⇘ High confidence in experiments and simulations



Remanent states after saturation along [001]



Collabo. Y. Samson (CEA-Grenoble)



Finite-differences method (JC Toussaint)

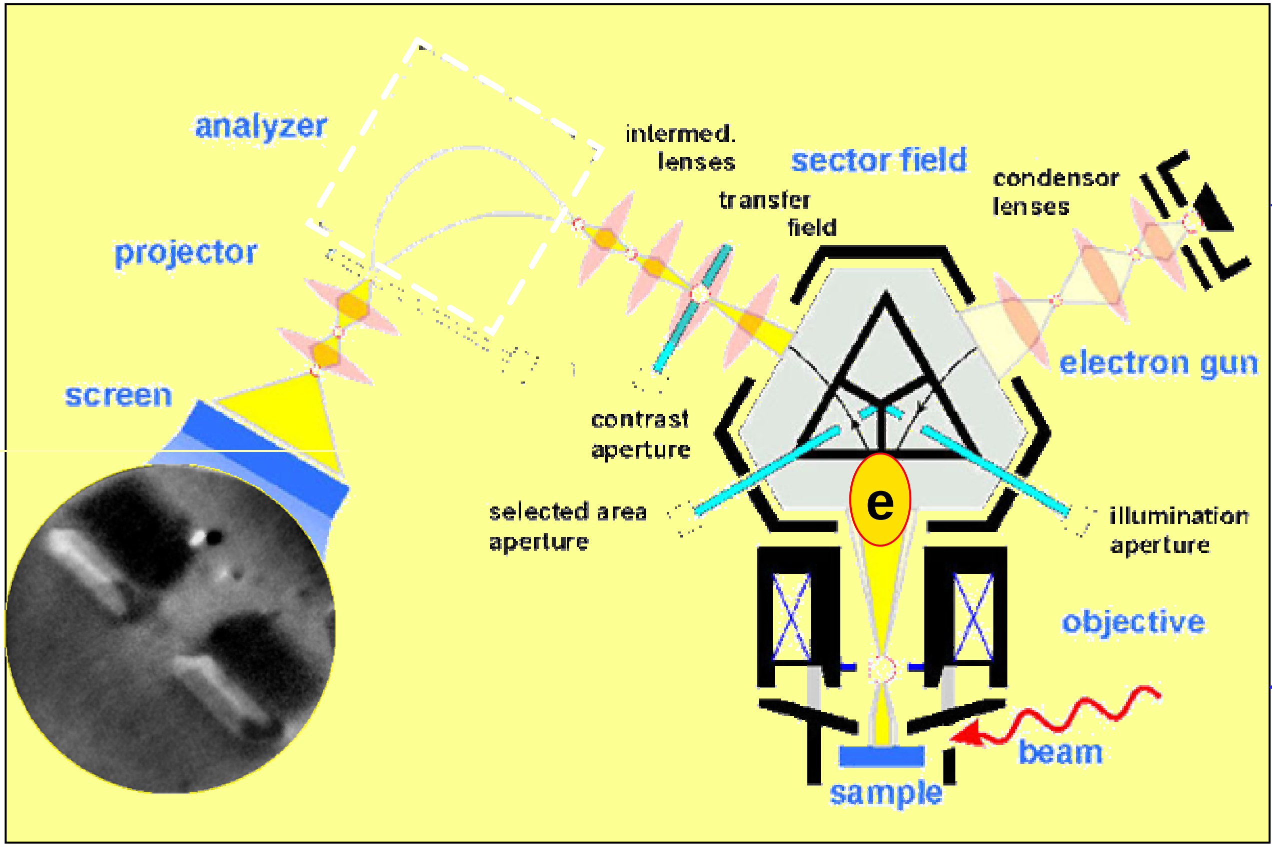
P.-O. Jubert *et al.*, Phys. Rev. B64, 115419 (2002)
P.-O. Jubert *et al.*, Europhys. Lett. 63, 135 (2003)

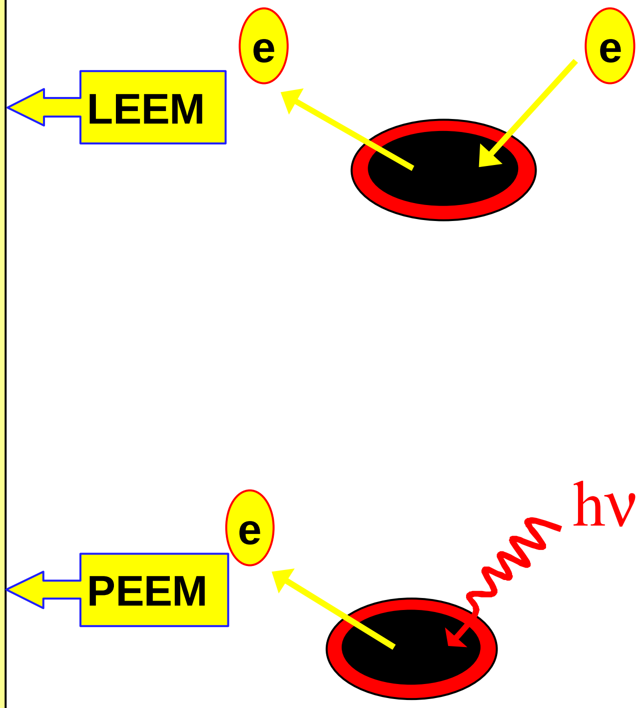
Need other imaging techniques

- Higher resolution
- Direct imaging of magnetization

XMCD-PEEM: X-ray Magnetic Circular Dichroism
PhotoElectron Emission Microscope

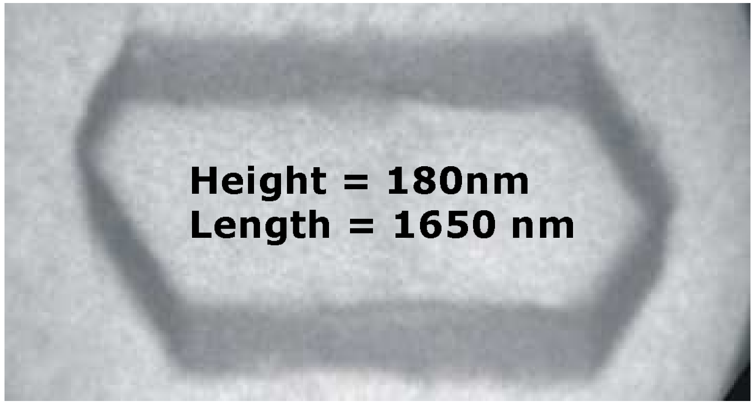
Based on LEEM instrument: Low-Energy Electron Microscope



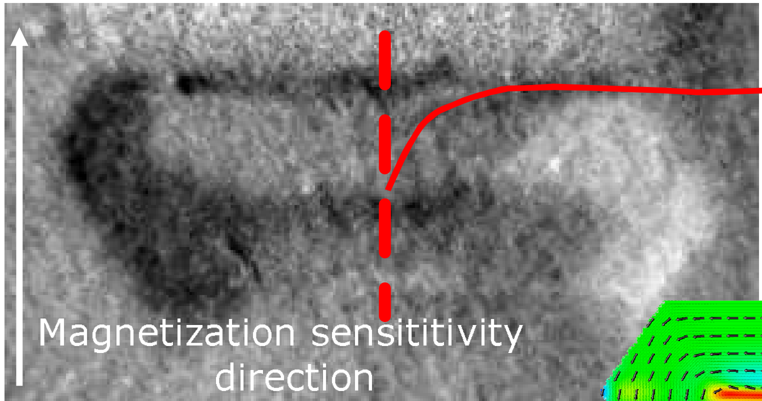


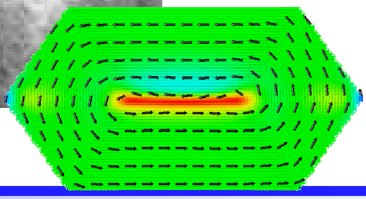
Thin versus thick dots:
From 2D nanostructures towards bulk materials

Experiment: topography (LEEM)



Experiment: surface magnetization (XMCD-PEEM)

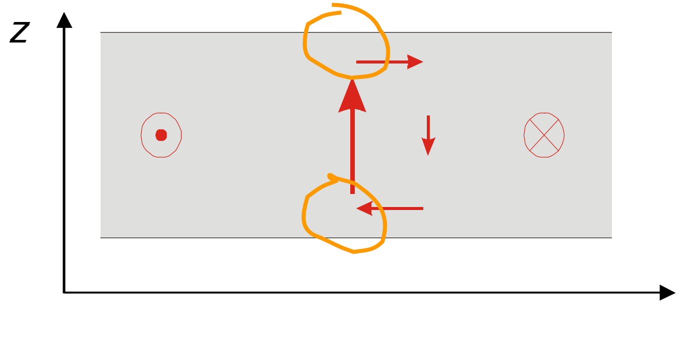


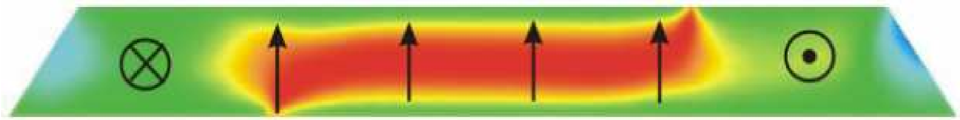


Néel caps occur to reduce surface and volume magnetic charges

$$\mathbf{M.n}=0$$

$$-\mathrm{div}\mathbf{M}=-\frac{\partial M_x}{\partial x}-\frac{\partial M_y}{\partial y}-\frac{\partial M_z}{\partial z}$$





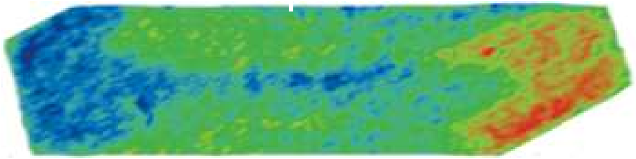
R. Hertel, MPI-Halle, now at IFF-Jülich

Previous simulations

R. Hertel *et al.*, PRB60, 7366 (1999)

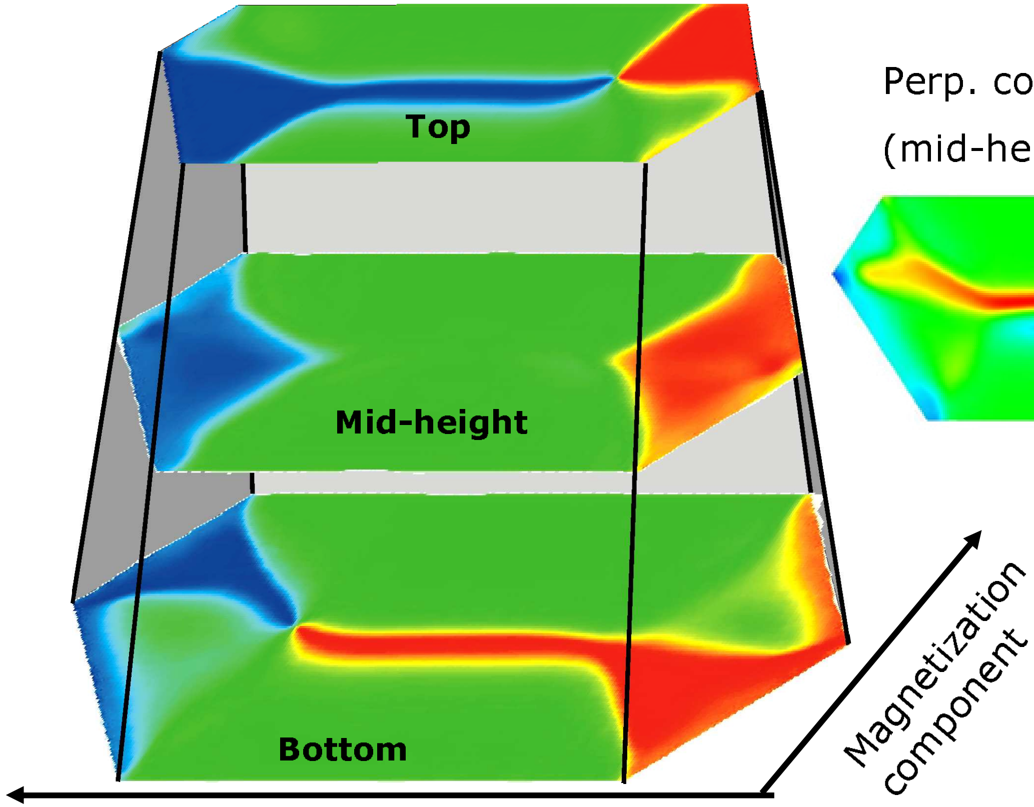
P.-O. Jubert *et al.*, Europhys. Lett. 63, 135 (2003)

Fe(110) DOTS — Flux-closure in 3D



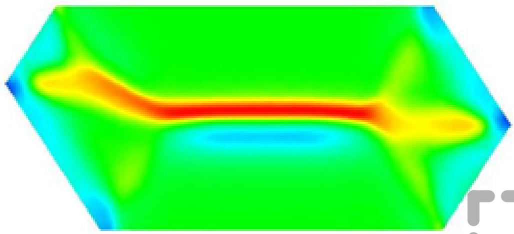
OF29

OF28

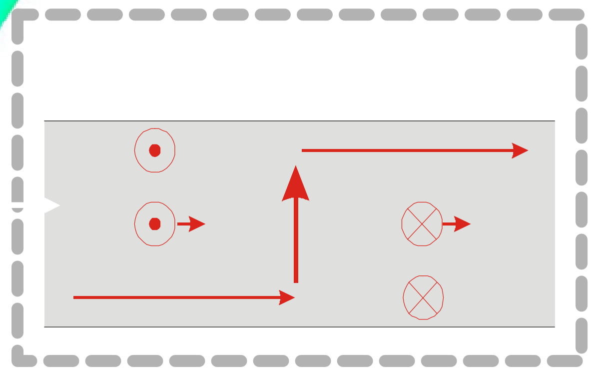


Perp. component

(mid-height view)



Assymetric Néel wall

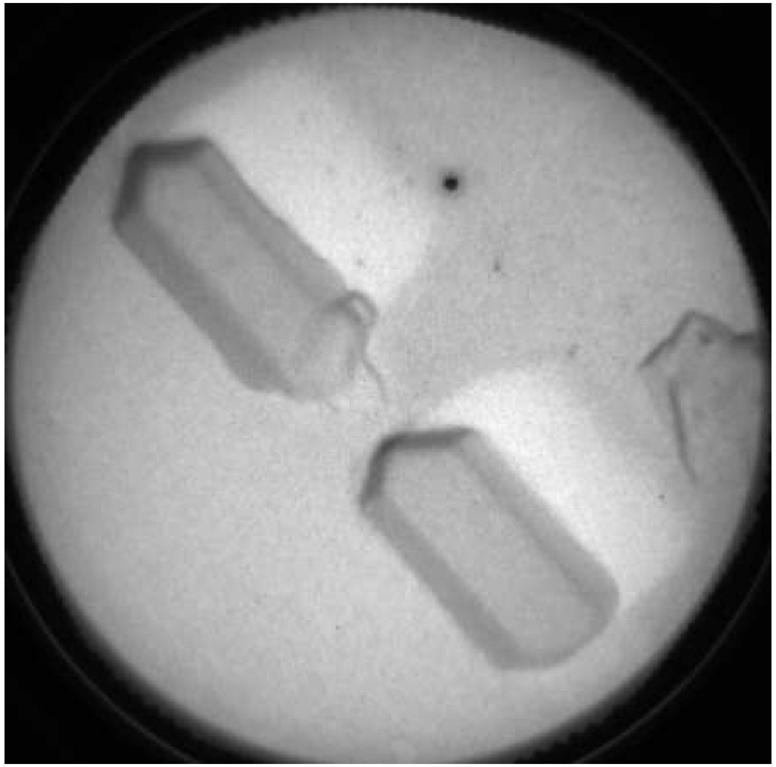


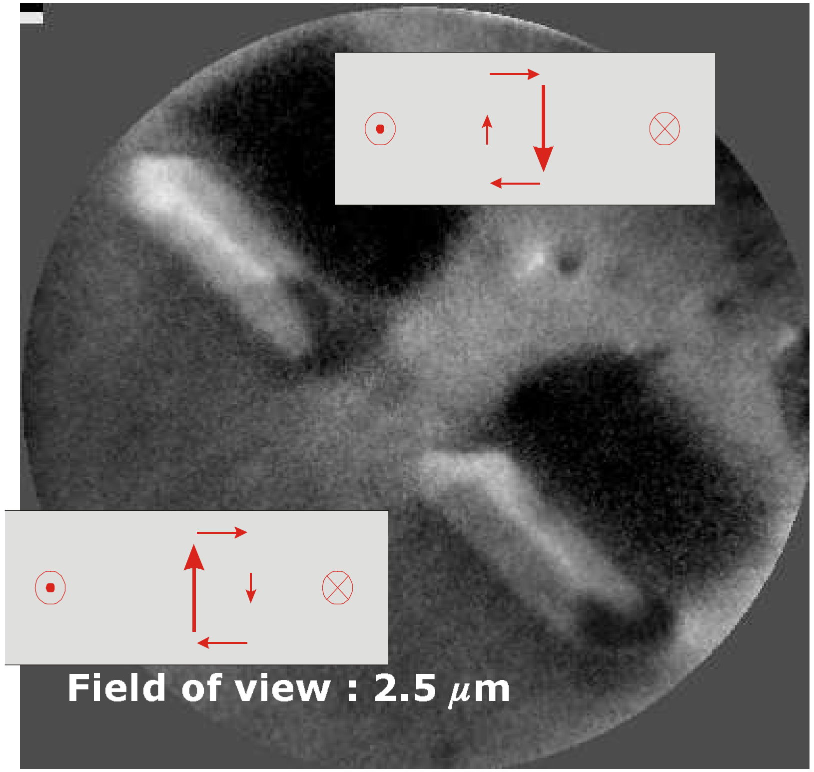
⤷ Flux-closure in 3D

Diapositive 10

OF28 Dresden JEMS04/Exposé/Néel caps.cdr
Olivier Fruchart; 03/06/2005

OF29 Visu tiltée de l'expérience: plaquette labo 2005-02
Olivier Fruchart; 24/01/2007

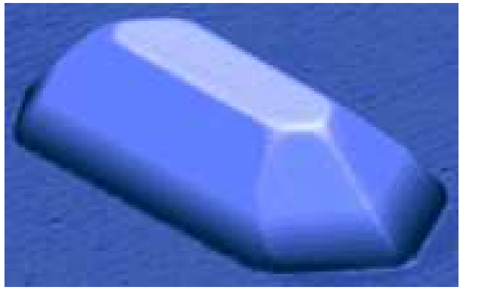


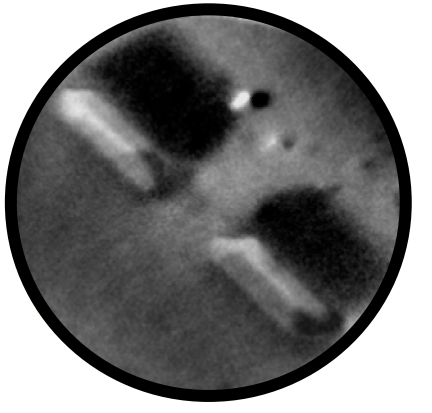


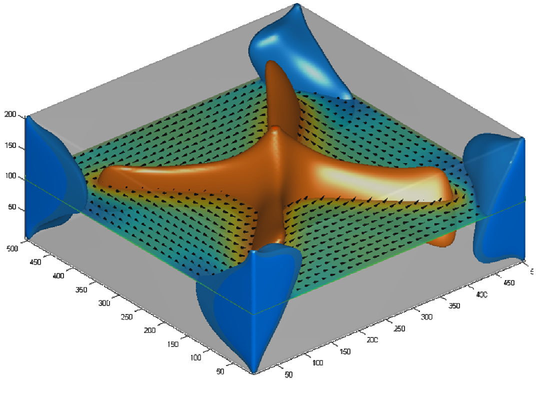
3 degrees of freedom

- Perpendicular magnetization of Bloch wall core
- Circulation of main domains (clock- versus anticlock-wise)
- Direction of Néel cap (Bloch wall asymmetry)

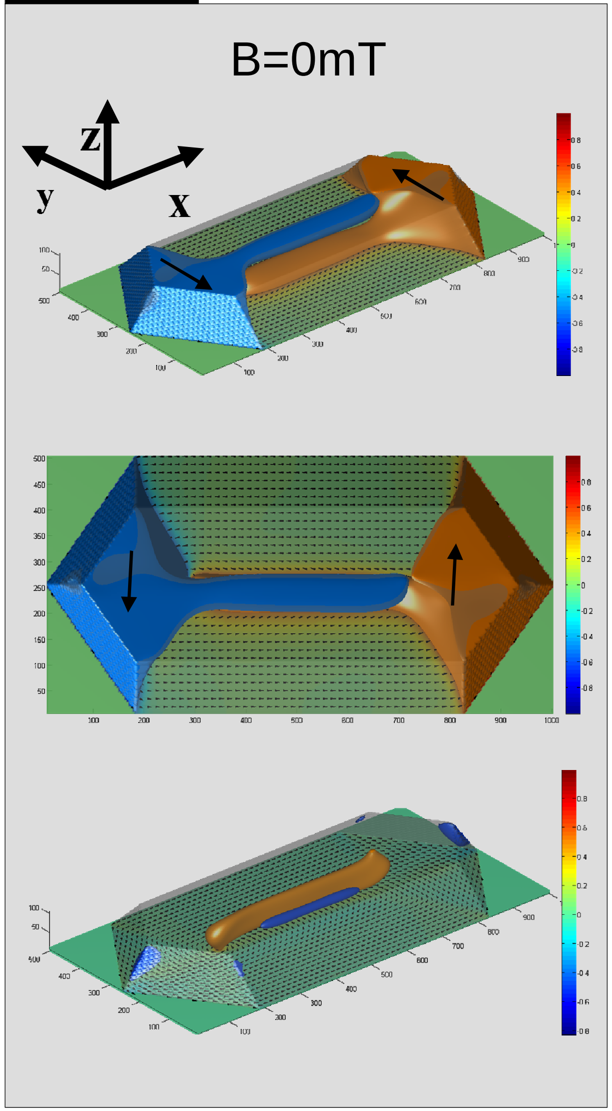
R. Hertel, O. Fruchart, S. Cherifi *et al.*, PRB 72, 214409 (2005)



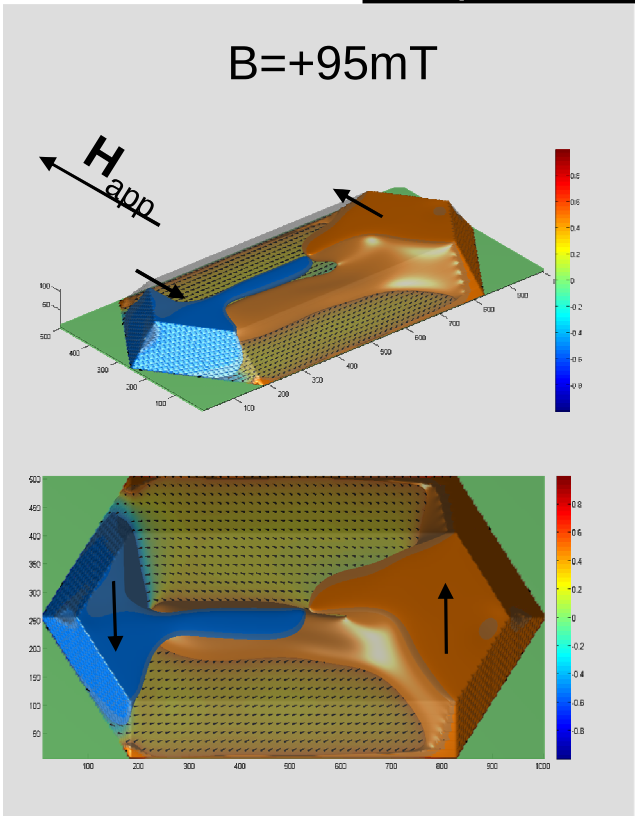


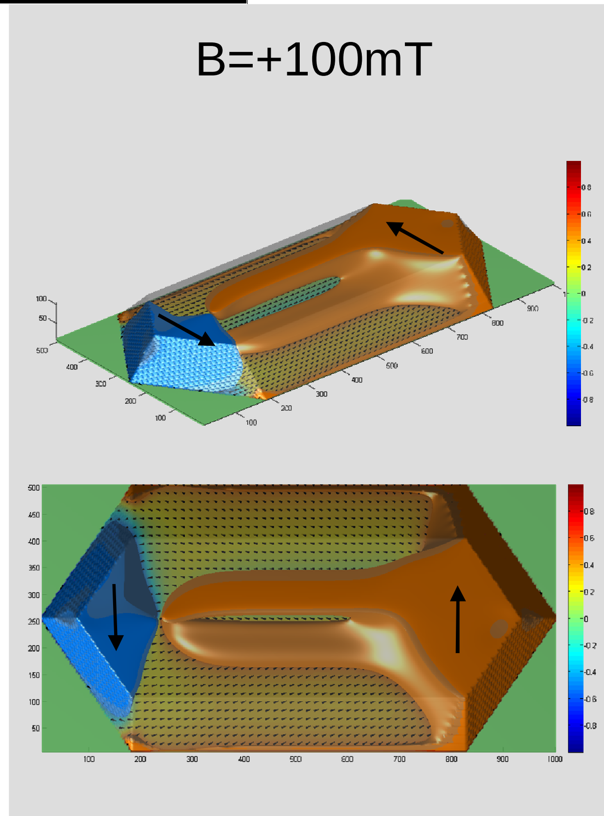


Zero field



In-plane transverse field

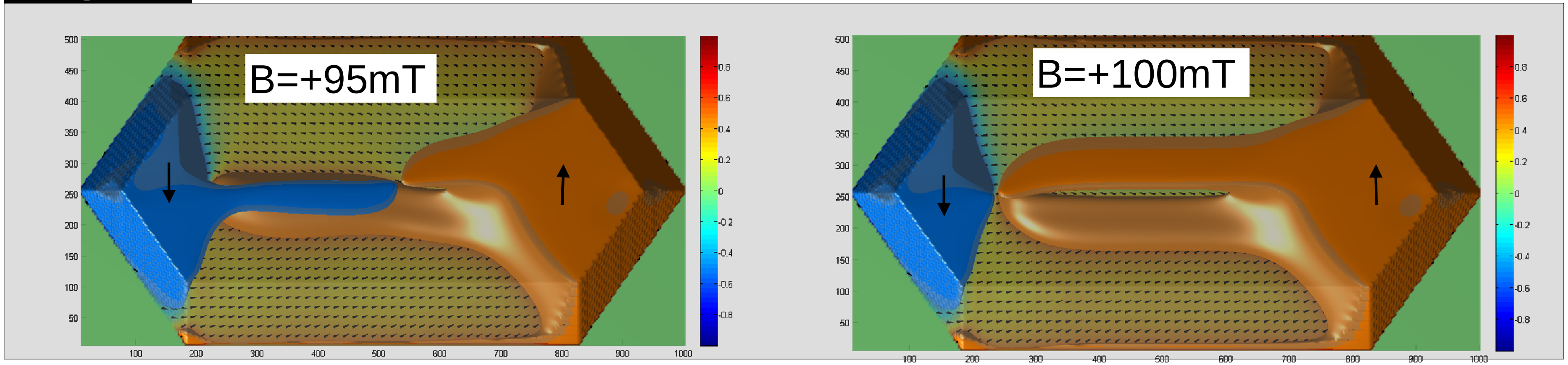


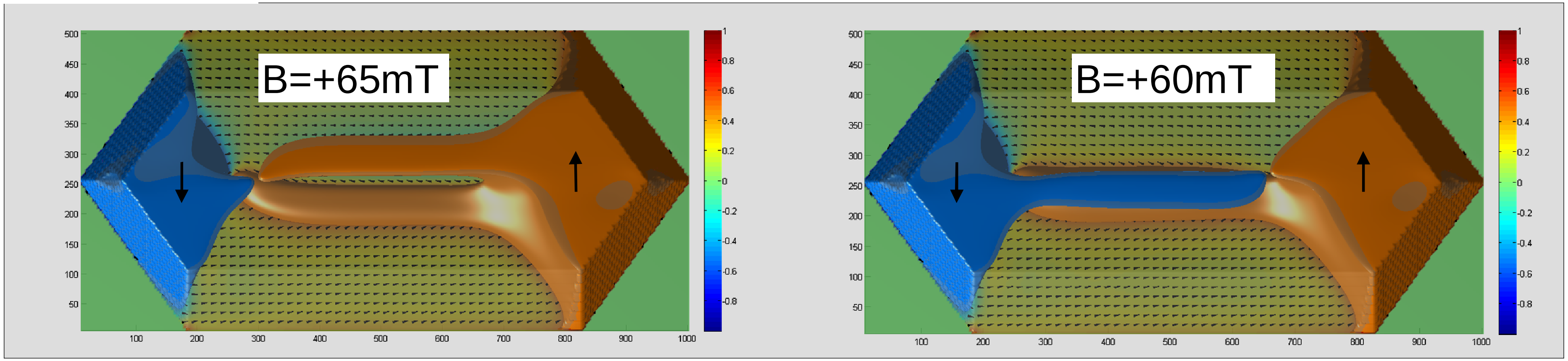


Size : 1000 x 500 x 100 nm

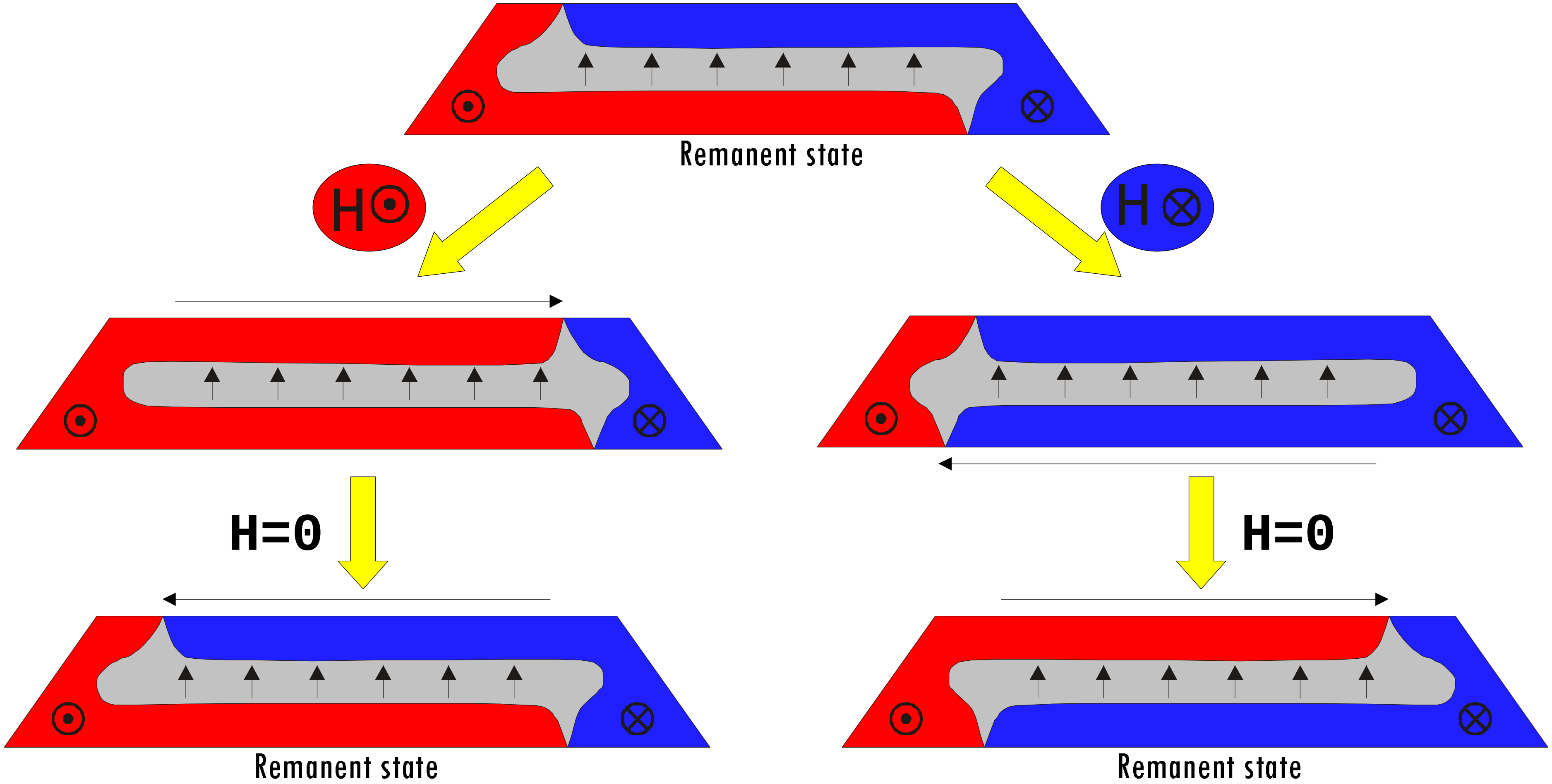
Micromagnetic simulations: J-C. Toussaint

Rising field



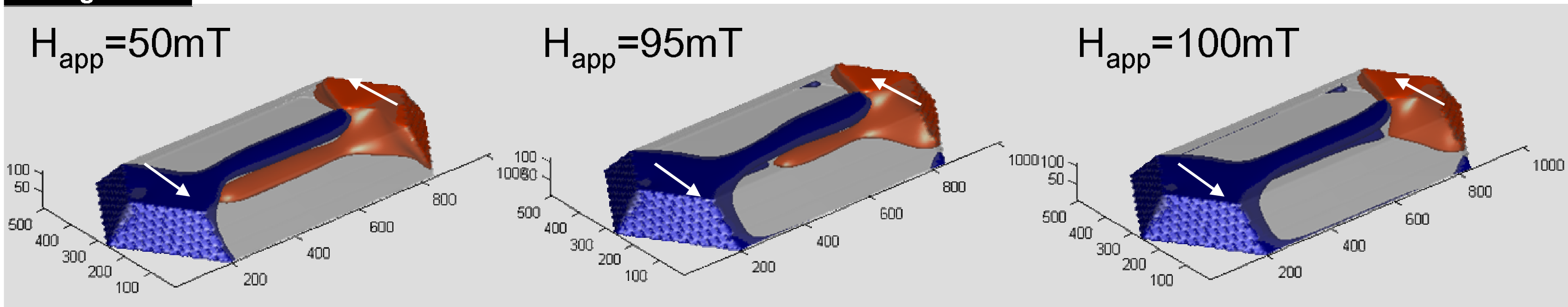


- Hysteresis of Néel caps (sub-feature of domain wall)
- Back to initial configuration > Can't we change remanent state?

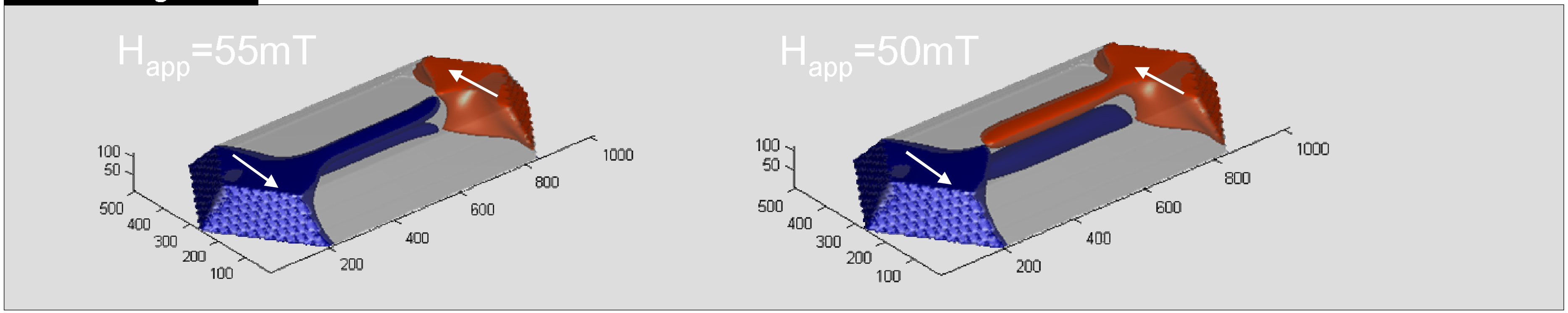


Direction of applied field drives remanent state at the top surface?

Rising field



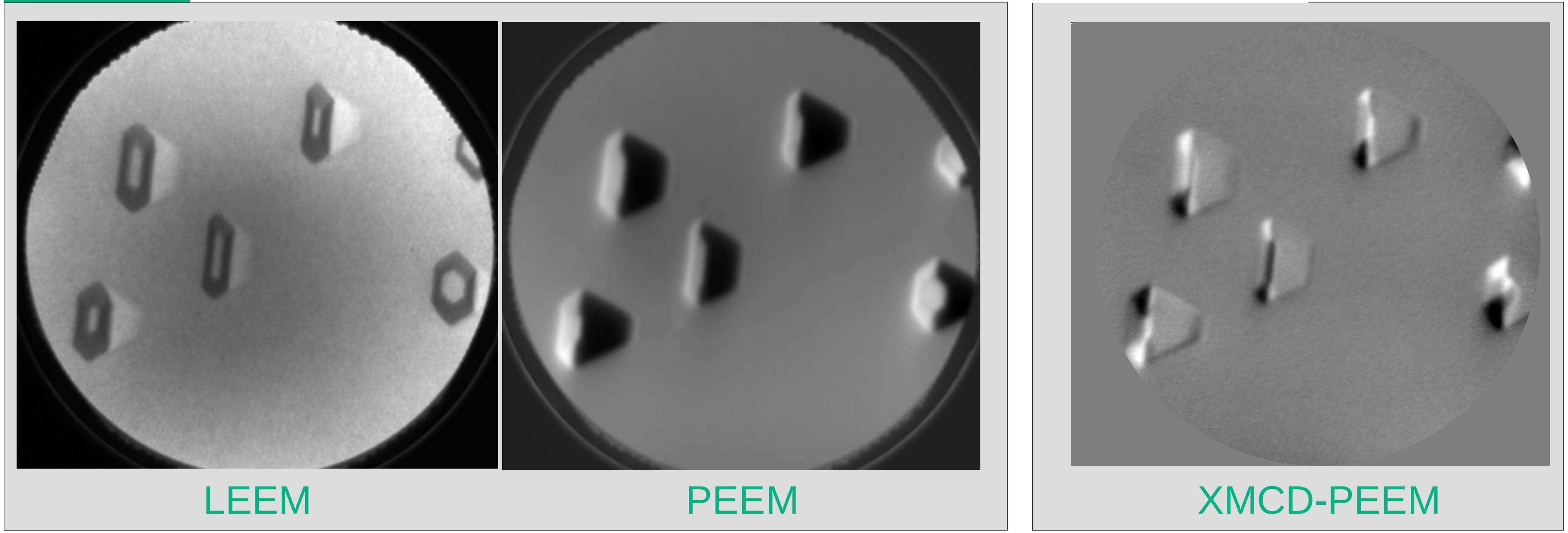
Decreasing field

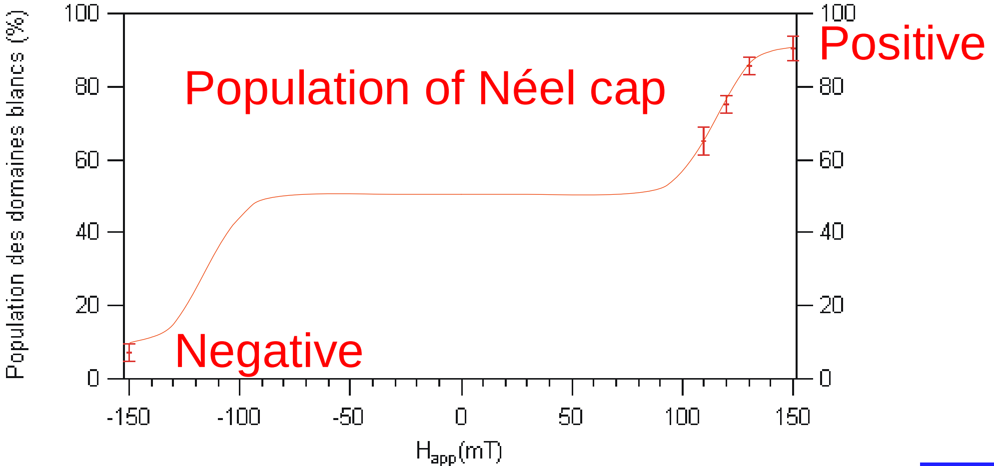


- Remanent state can be switched.
- Remanence of Néel cap is opposite to applied field

Topography

Field of view: 5μm





(Coll. R. Belkhou, N. Rougemaille, Elettra-Soleil)

Experiments: 95% switching.

Hubert's book:

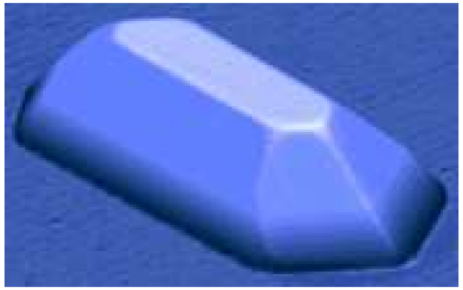
The calculation of domain wall structure is by far the most important contribution of micromagnetics in the analysis of magnetic domains. This is true for two reasons.

(1) It is in most cases difficult to isolate a single wall from its neighbours to measure its properties

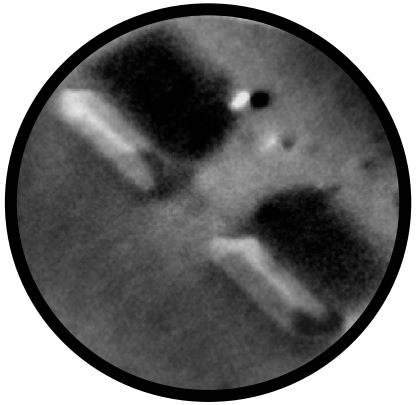
(2) Experimentally, domain walls are difficult to access because they change their properties at surfaces where they can primarily be observed

A. Hubert and R. Schäfer, Magnetic domains, Springer (1999, 2001)

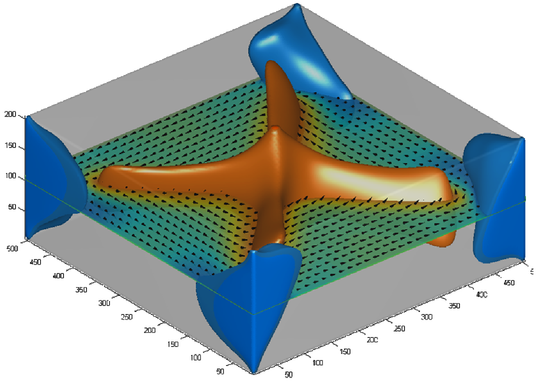
1. Self-assembled Fe(110) dots: a model system for micromagnetism

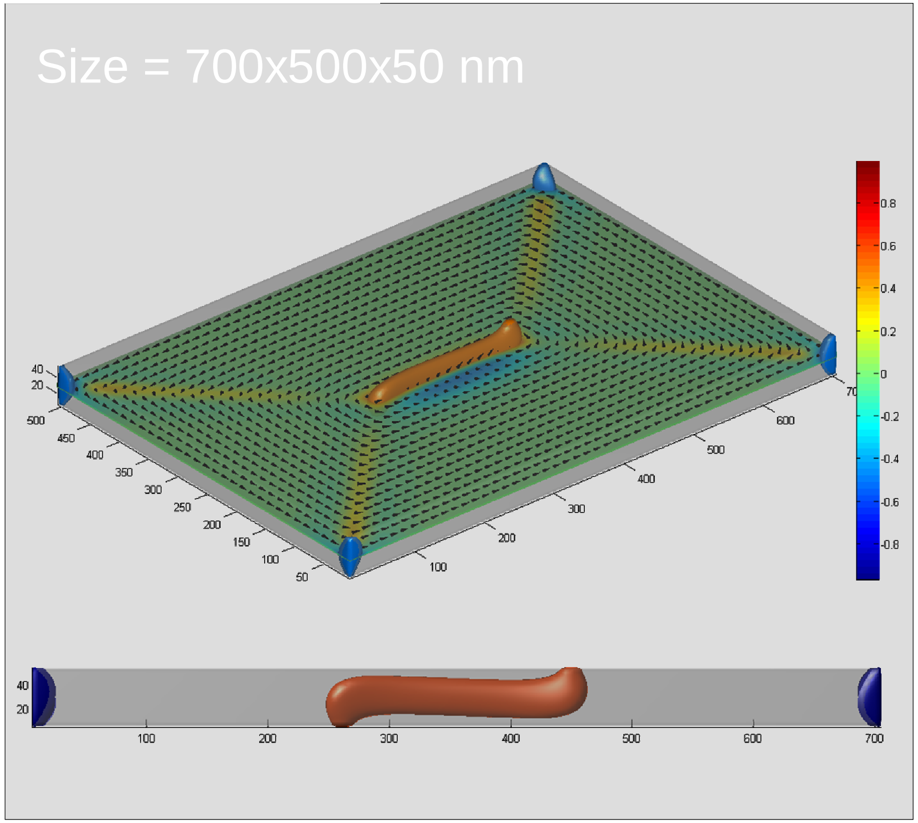


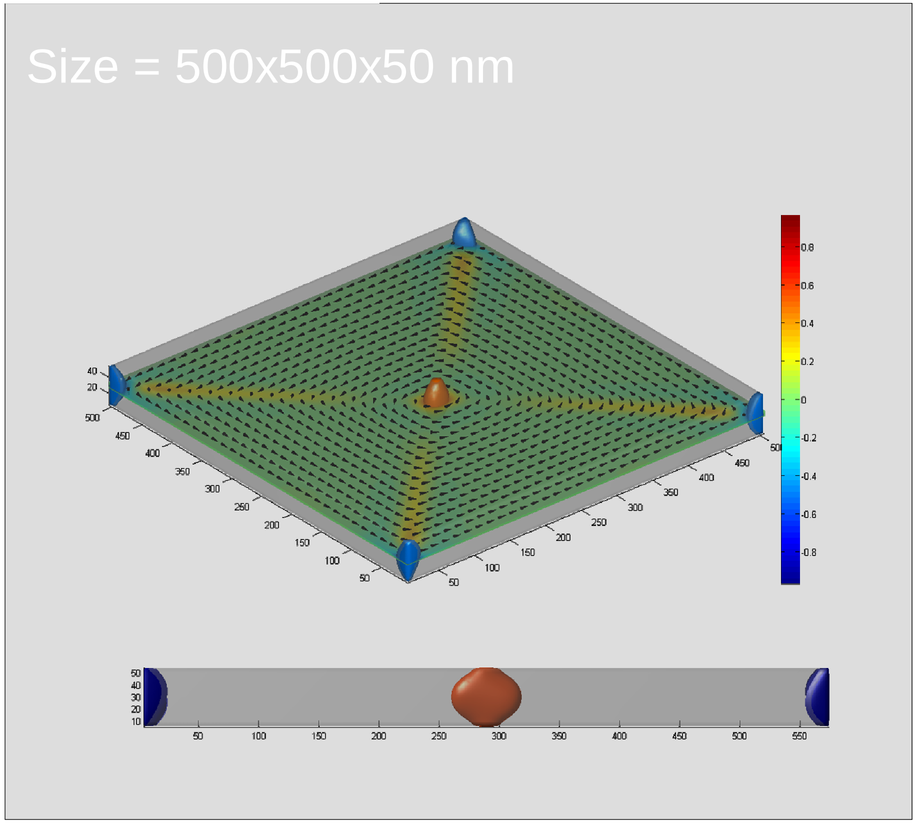
2. Magnetization reversal of Néel caps in Bloch domain walls



3. Cross-over from a domain wall to a magnetic vortex

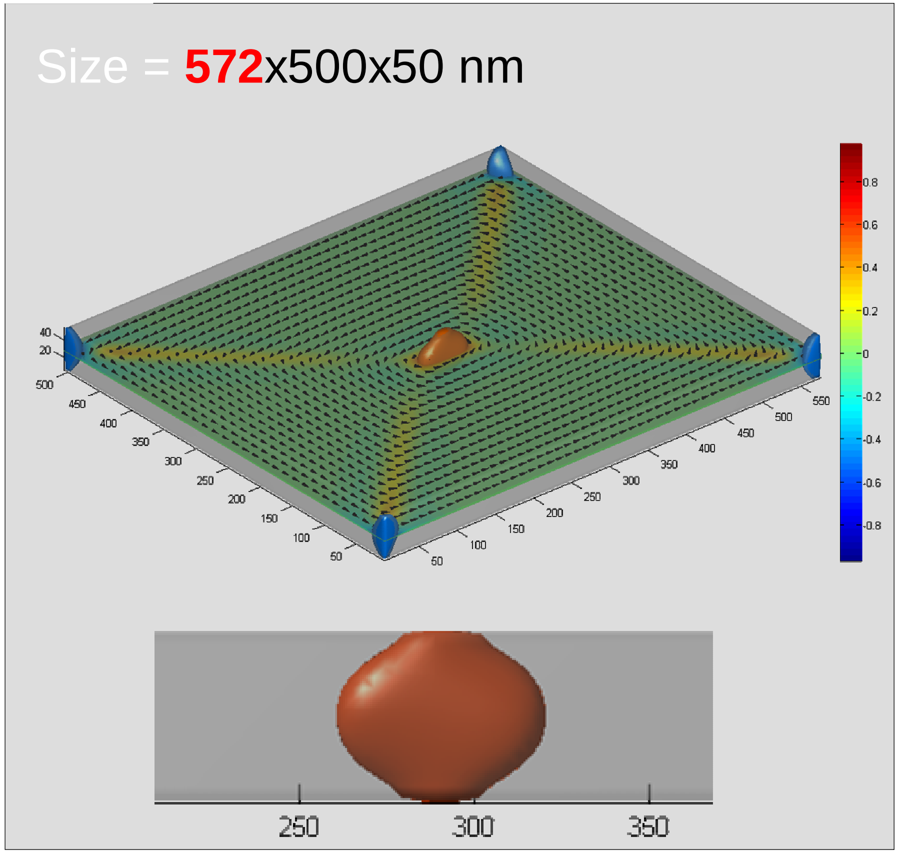




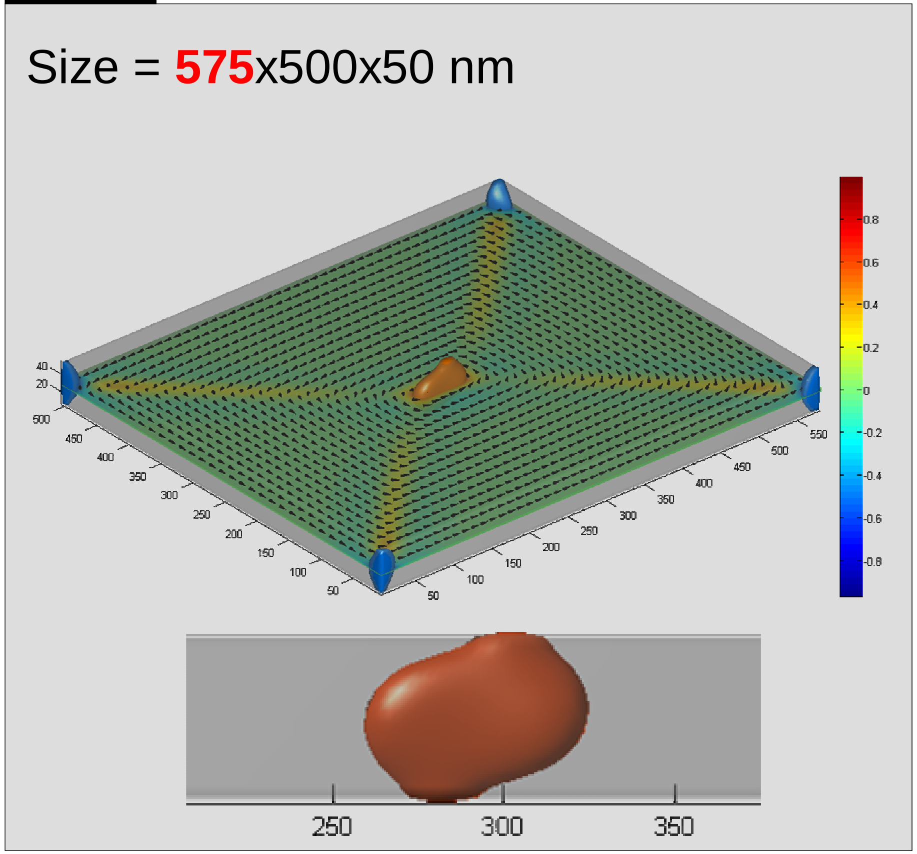


Questions

- How does the transition occur?
- Is there a minimal length for domain walls?



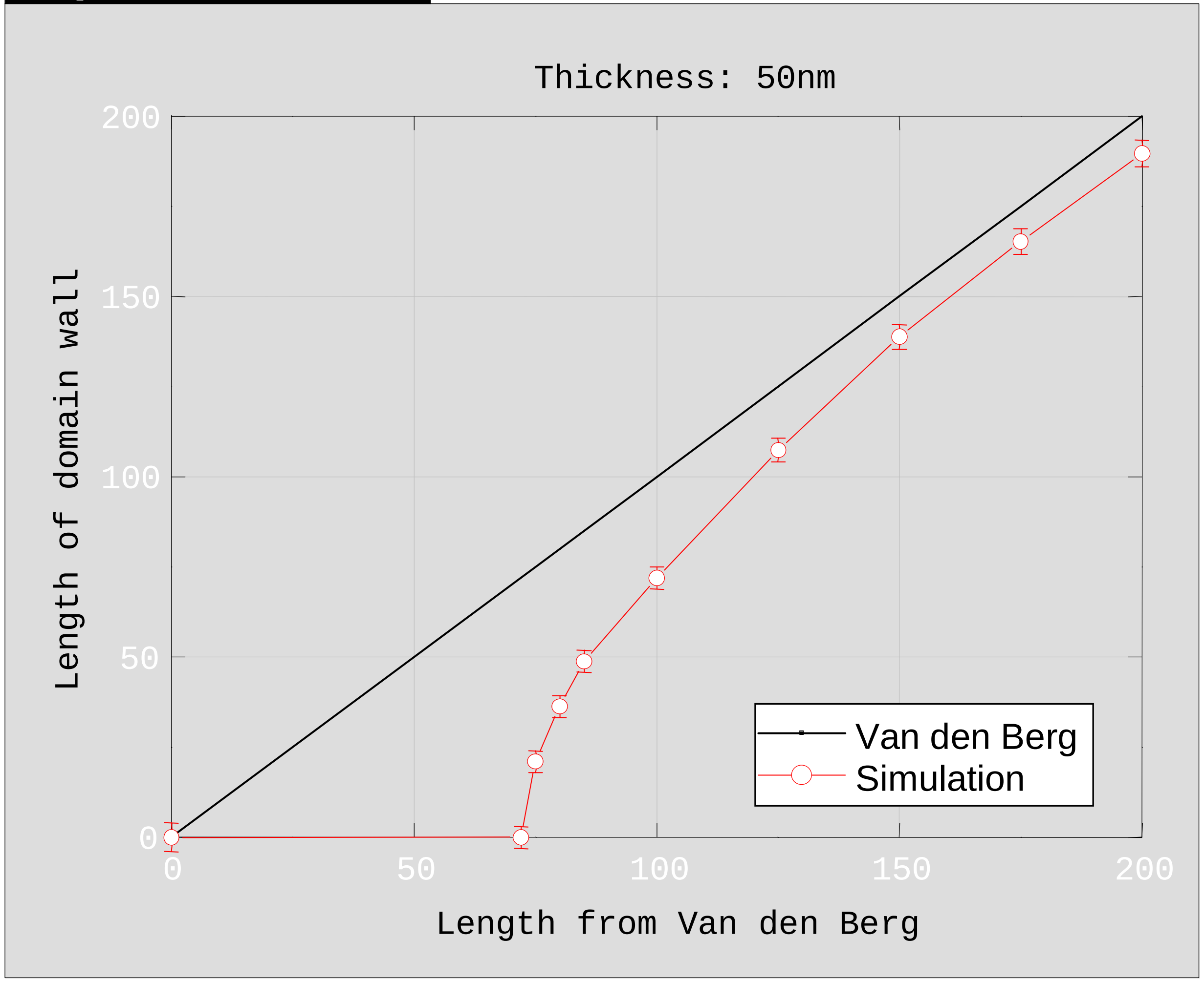
Wall



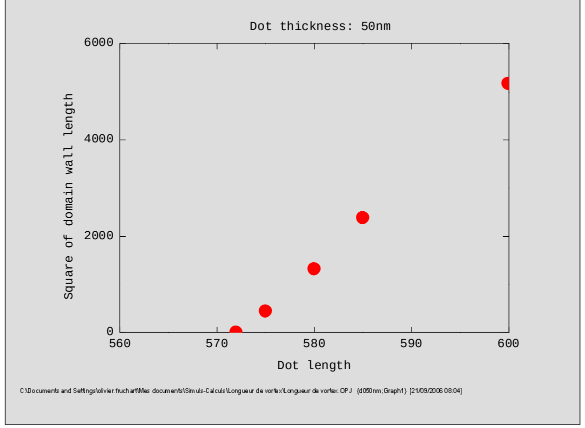
Questions

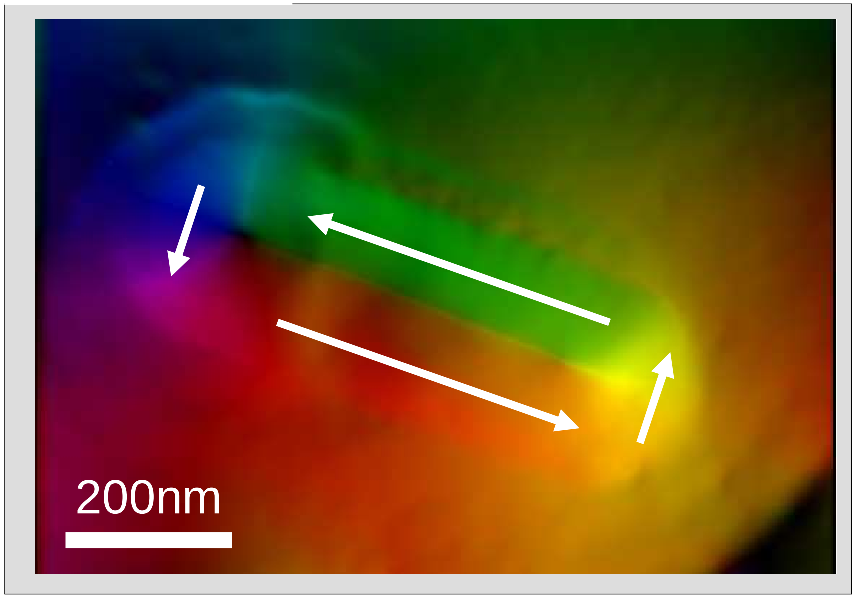
- Is there a minimal length for domain walls?
- How does the transition occur?

Length of domain wall

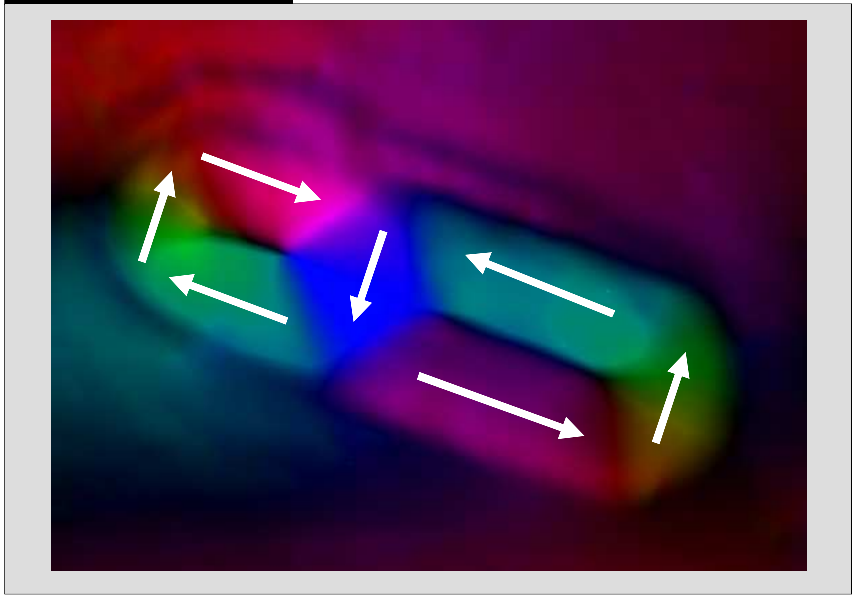


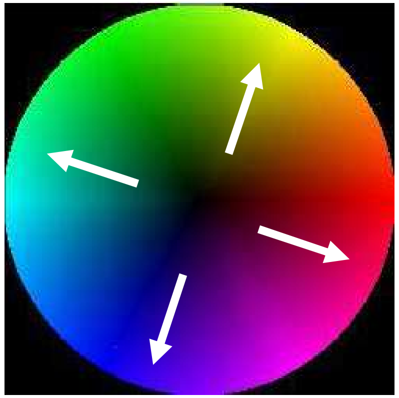
Squared length of domain wall





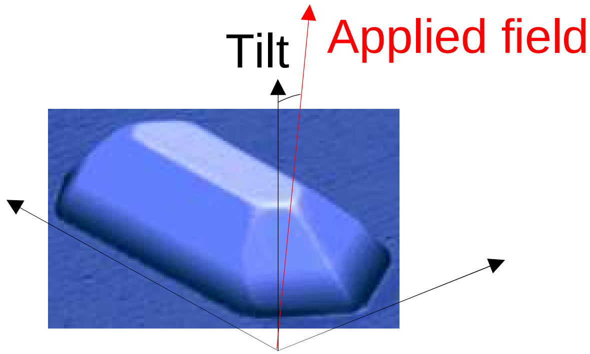
Diamond state



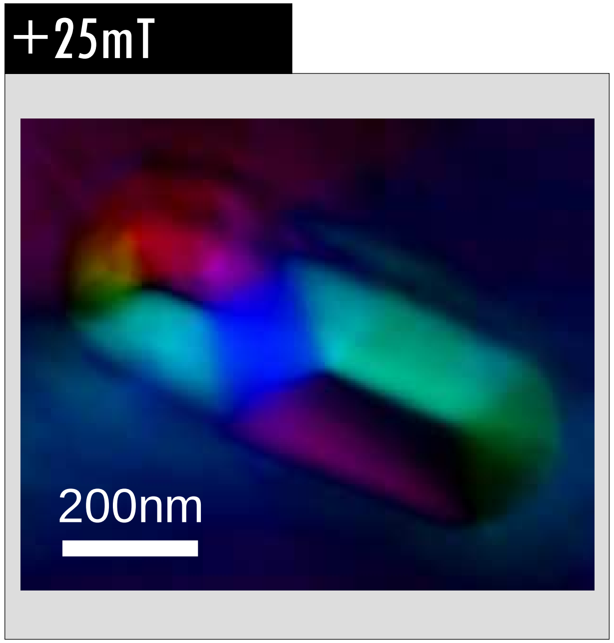


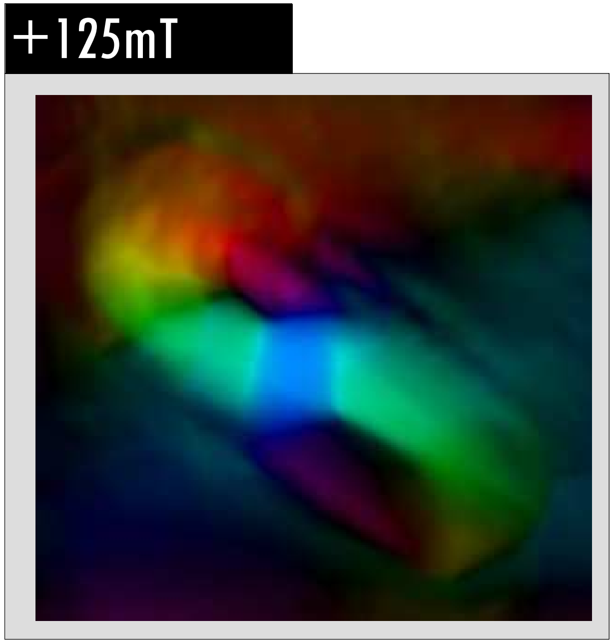
In some cases the flux-closure pattern at remanence can be controlled via a sequence of applied field

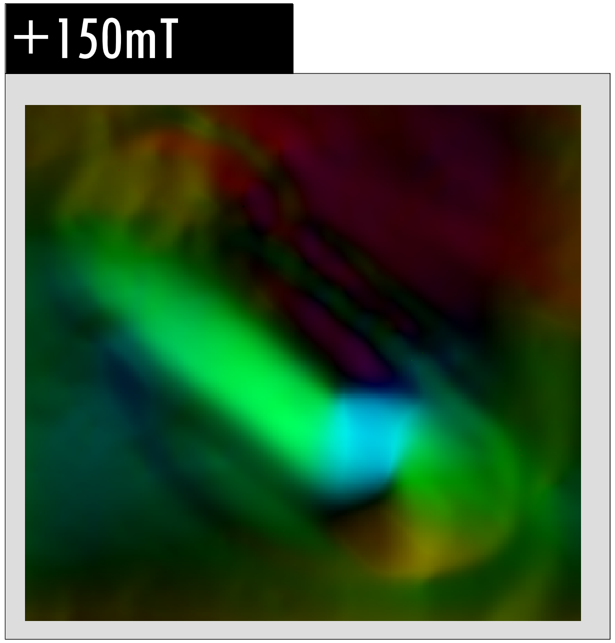
Technical note: TIE imaging mode

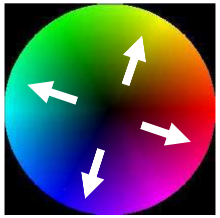


On this page: tilt = 8°







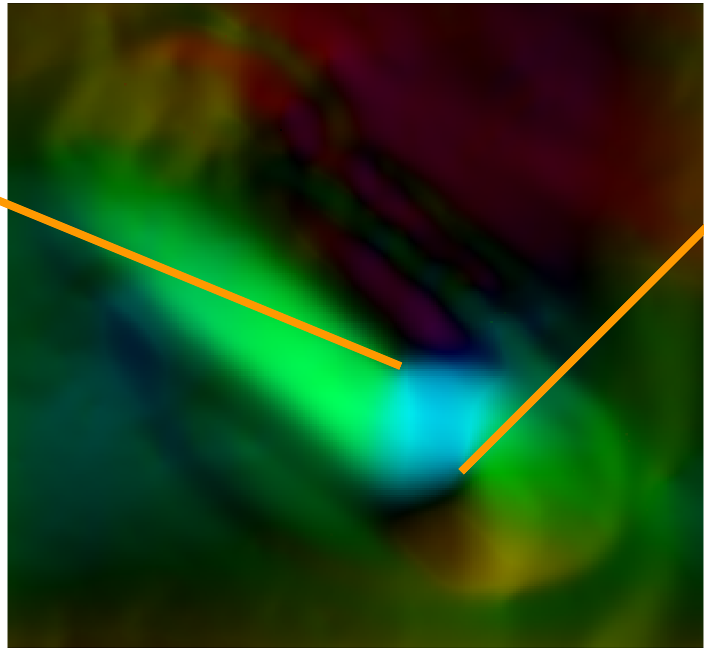


External applied field as a mean to control a domain wall length

Technical note: TIE imaging mode

Corresponding fluctuation on the opposite side

014.avi



Vortex versus wall fluctuation

008.avi

(Full dot)

011.avi

(Zoom)

Laboratoire Louis Néel (CNRS), Grenoble (France)

O. Fruchart, **F. Cheynis, P.-O. Jubert (now at IBM-Almaden), H. Haas, C. Meyer**
Technical support: **V. Santonacci, Ph. David, A. Liénard, S. Biston, S. Pellé…**

Growth and magnetism

J.-C. Toussaint, N. Collins, H. Szambolics

Computer micromagnetics

S. Cherifi, J. Vogel, N. Rougemaille,

ELETTRA Sincrotron, Trieste (Italy)

A. Locatelli, S. Heun, R. Belkhou, N. Rougemaille

PEEM

MPI für Mikrostrukturphysik, Halle (Germany)

R. Hertel (now at IFF-Jülich), J.Kirschner

Computer micromagnetics

DRFMC, Grenoble (France)

A. Masseboeuf, P. Bayle-Guillemaud, A. Marty

Lorentz Microscopy