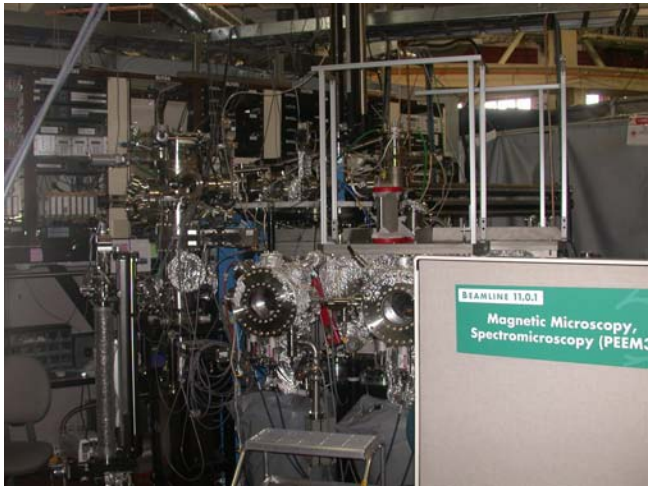
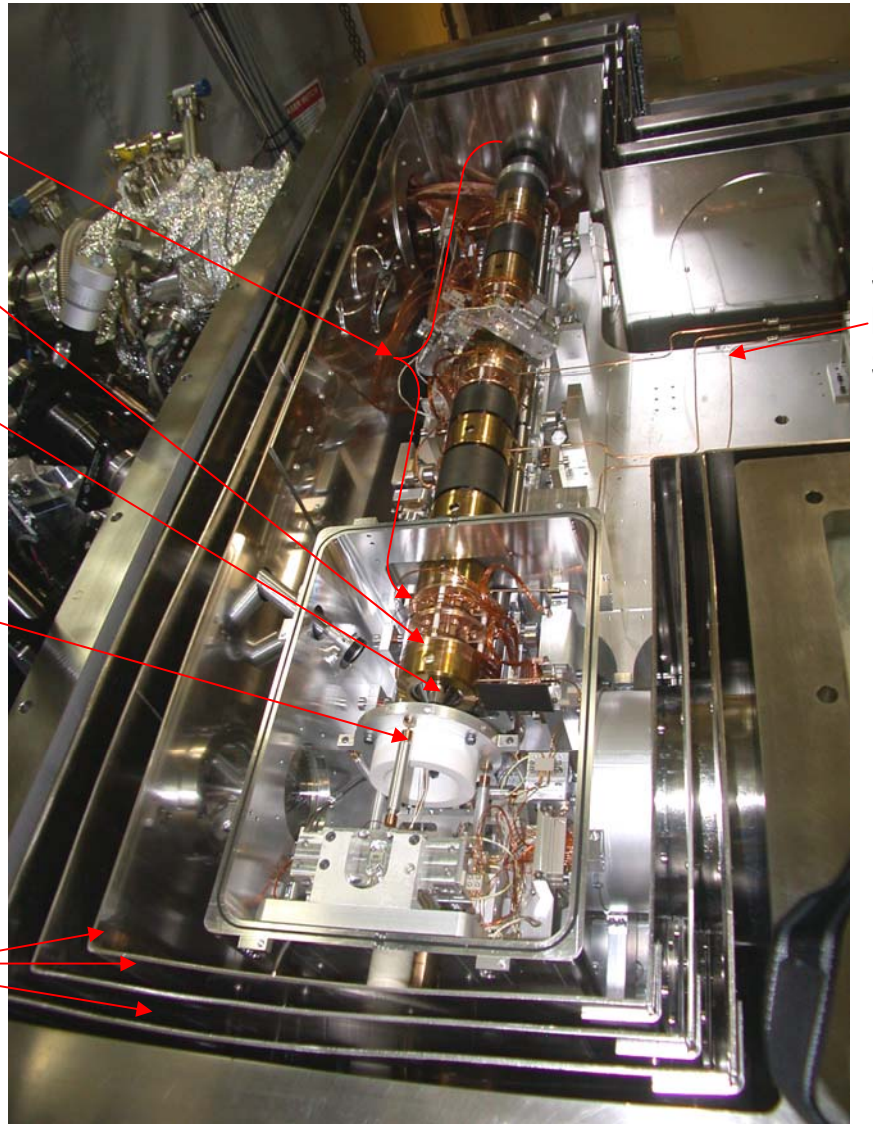
Low-Temperature Spectromicroscopy Using the Advanced Light Source PEEM-3

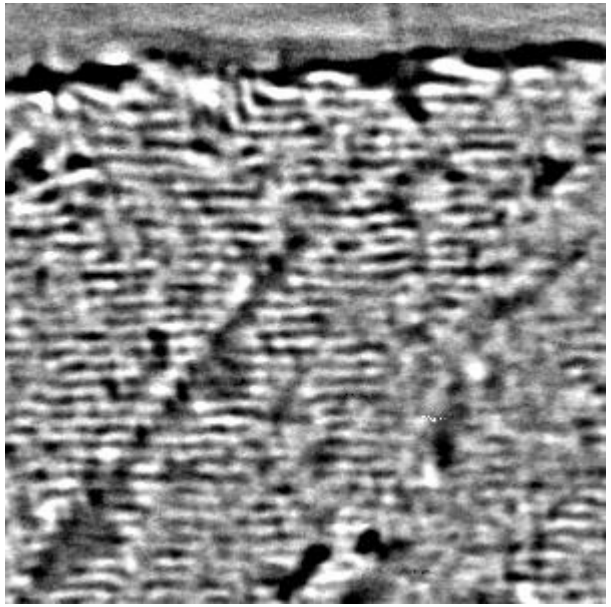




Applications:

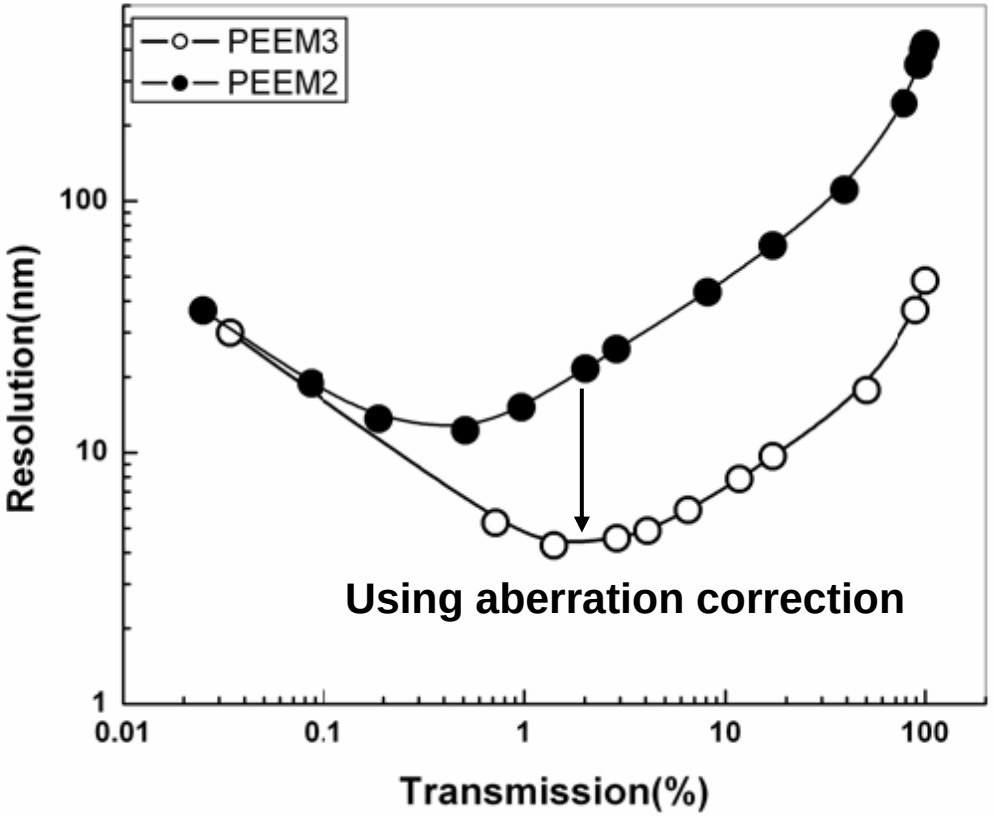
- **Materials and Surfaces**
- **Magnetism**
- **Multiferroics**
- **Polymers**
- **Dynamics**

Spatial Resolution



Element-resolved X-PEEM image of a 25 nm thick Cr/Si layers.

Simulation

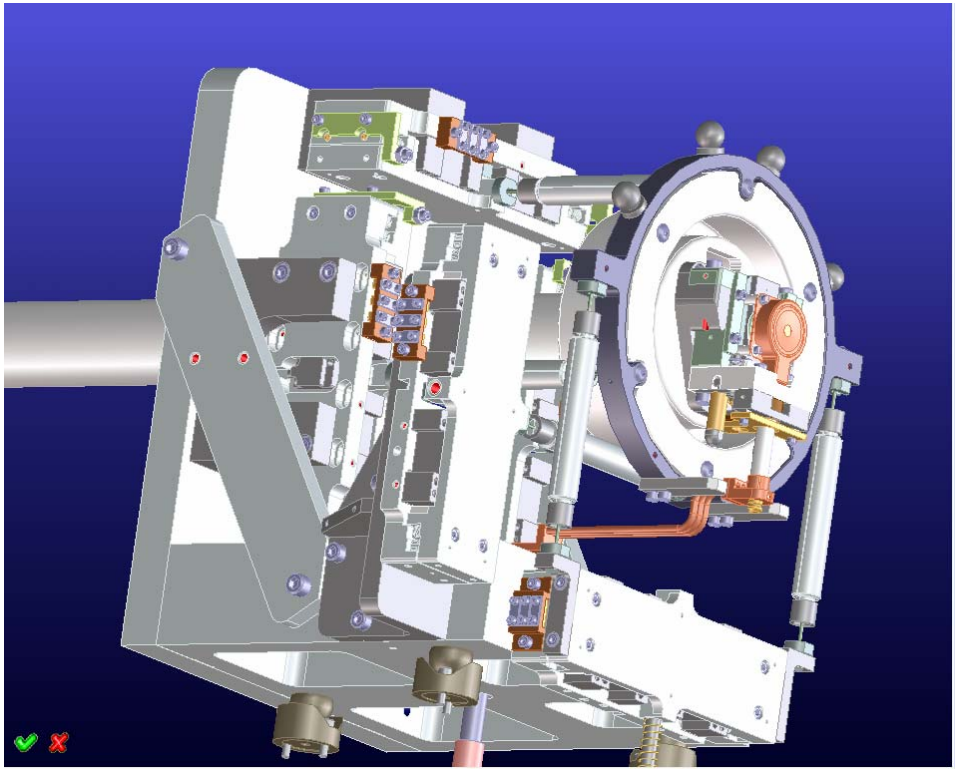


After aberration correction:

5-fold improvement of spatial resolution at a few % transmission (goal 5 nm)

20-fold improvement of transmission at several 10 nanometer spatial resolution.

PEEM-3 Manipulator

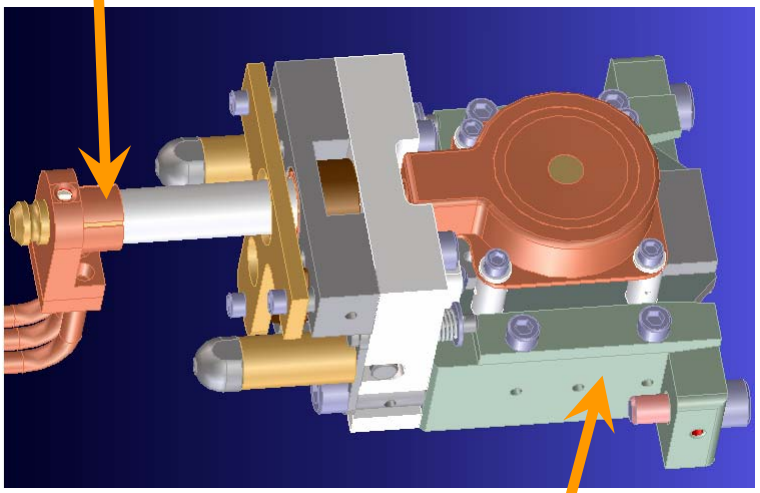


- 6 strut sample manipulator
- Motorization using picomotors
- Large range of motions
- Built for fully automated sample transfers

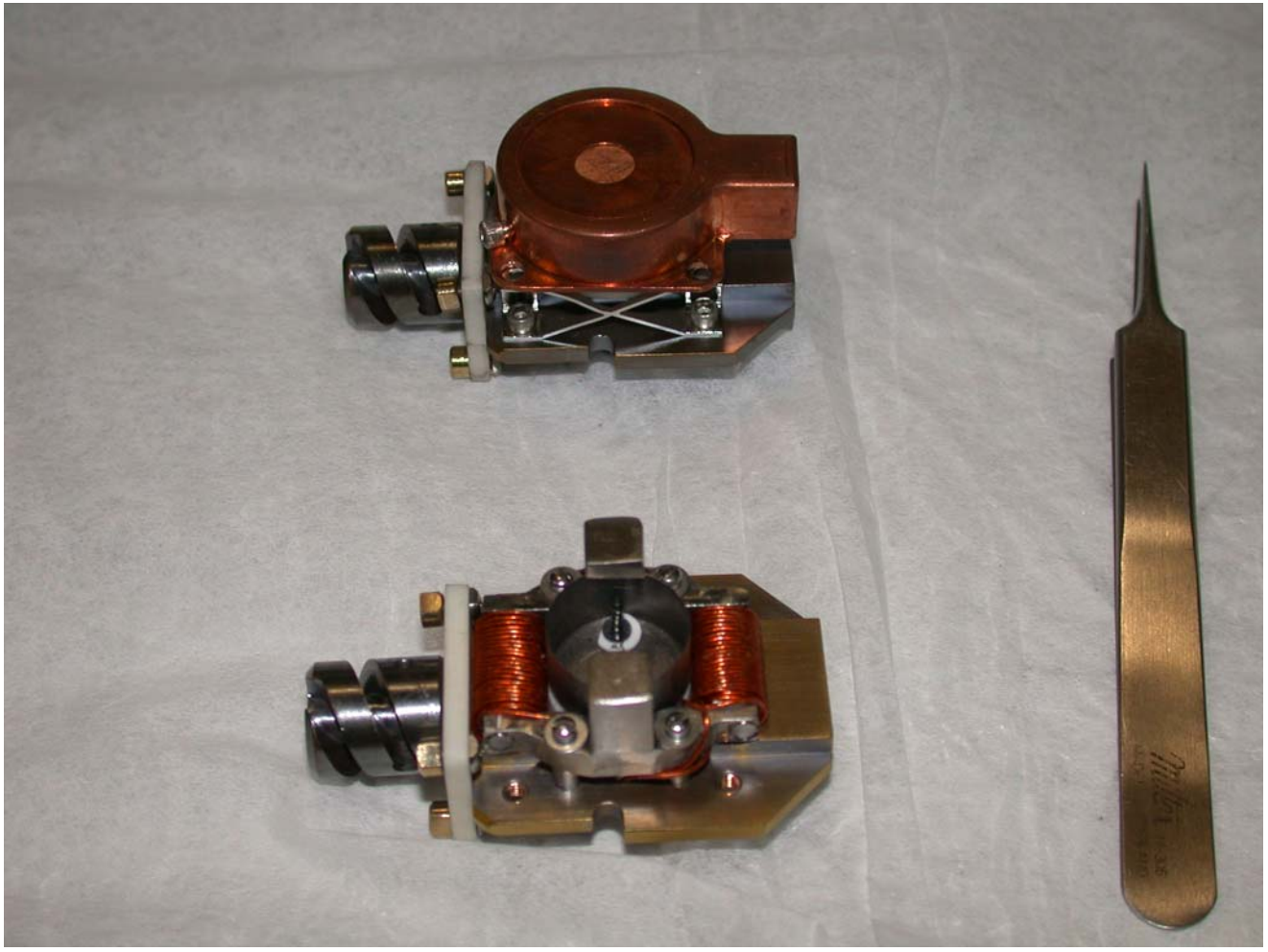
Built by LBNL engineering division (R. Duarte, T. Miller, N. Kelez et al.)

- Vibrations effectively decoupled
- Electrical isolation
- Small cooled volume
- Built-in electromagnet at RT
- Flexible design for large samples of different size and shape.

To cryostat
Ground potential

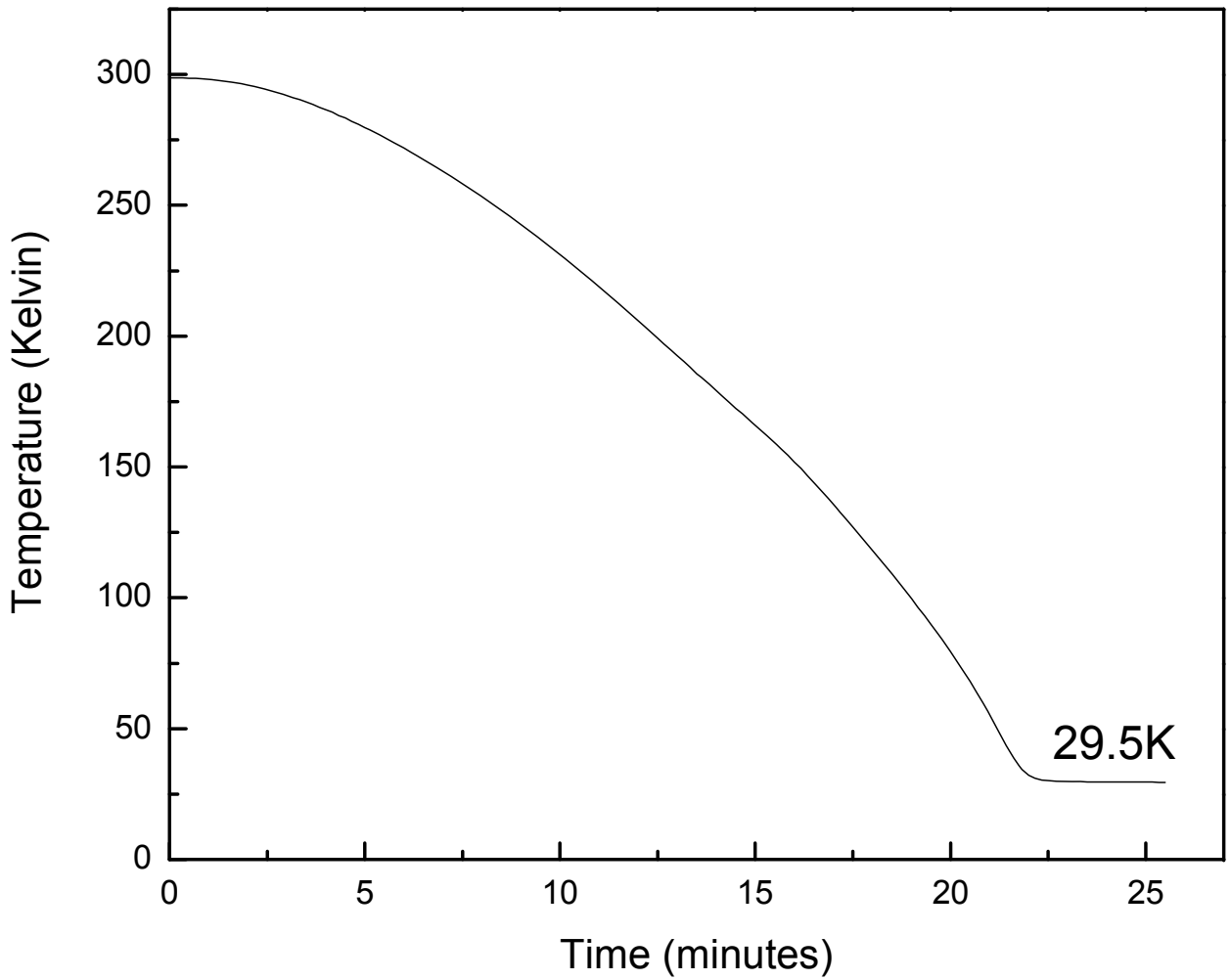


Sample Holder



(Inspired by Elmitec design)

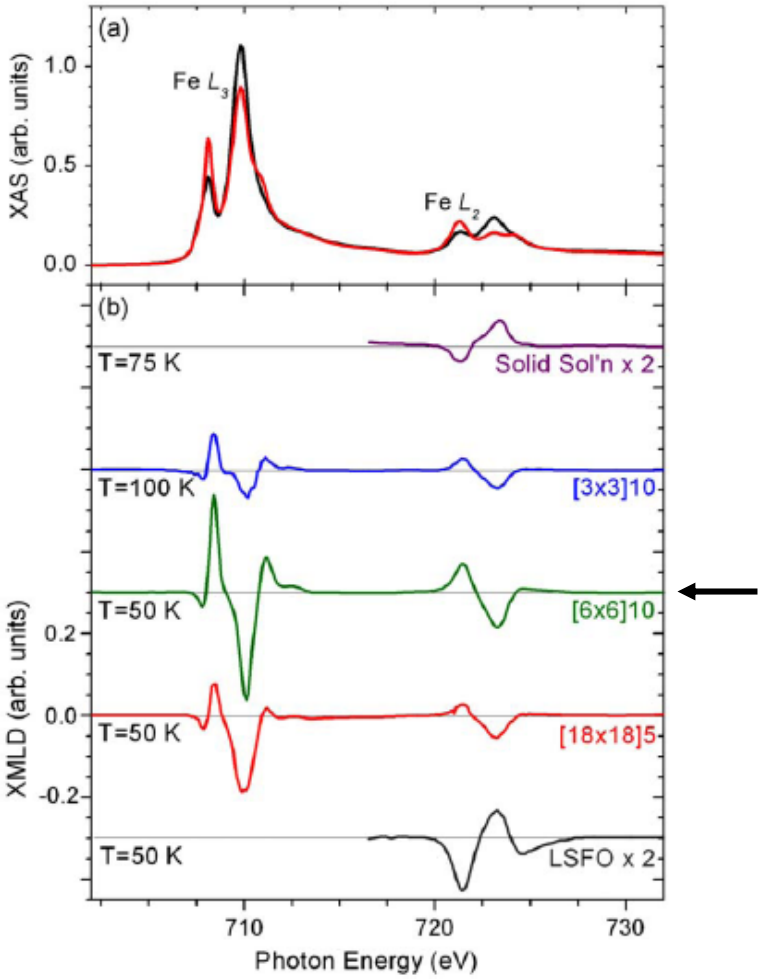
Cooling Performance Using Liquid He



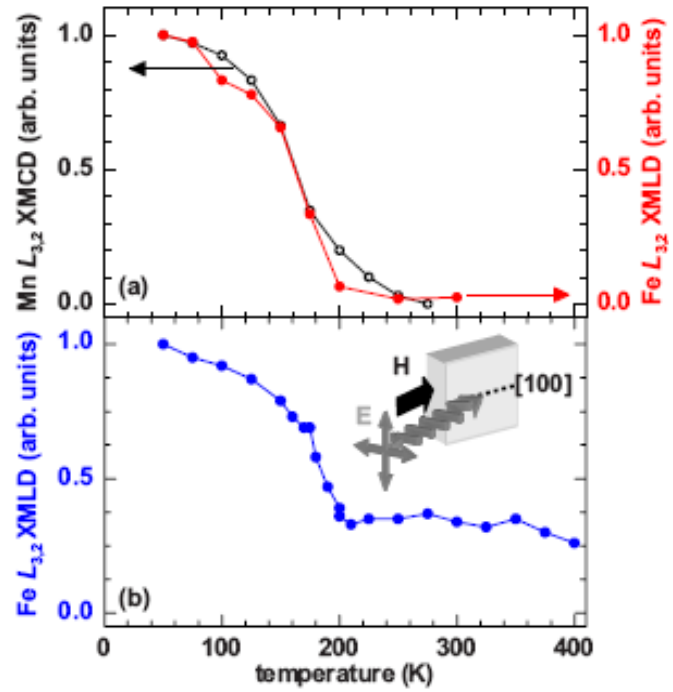
Measured using a type 10 Si diode close to the sample

Competing Interactions in FM/AFM Perovskite Superlatiices

LSFO/LSMO multilayers



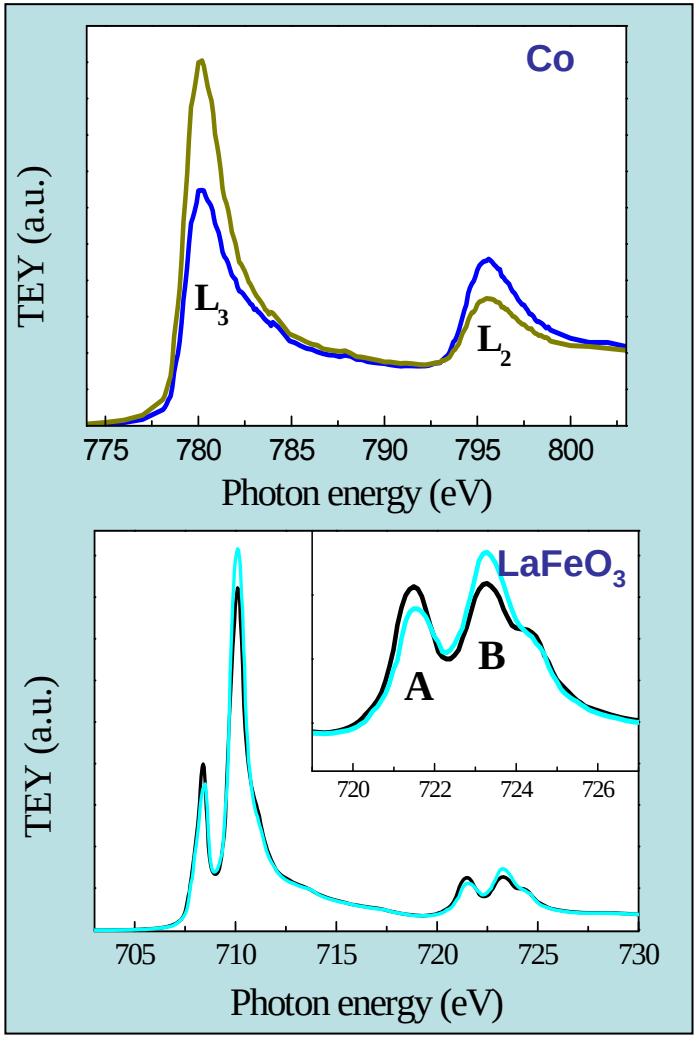
F. Yang, Y. Takamura, et al., UC Davis

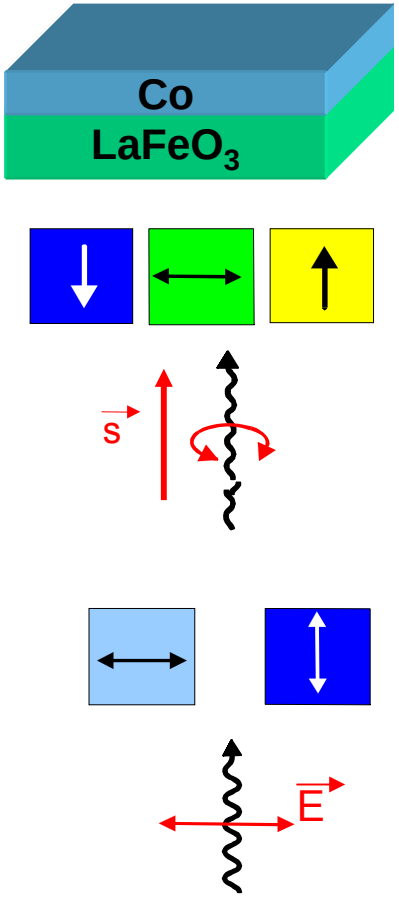


Spin flop coupling

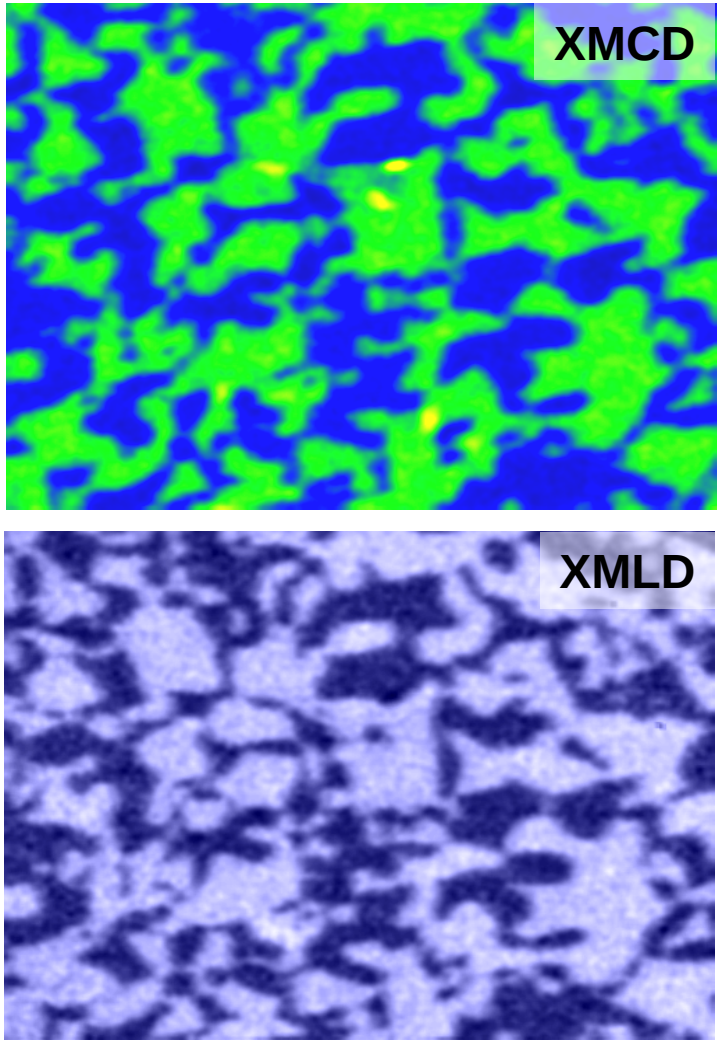
XMCD and XMLD Imaging of Ferromagnets and Antiferromagnets

Spectroscopy





Microscopy



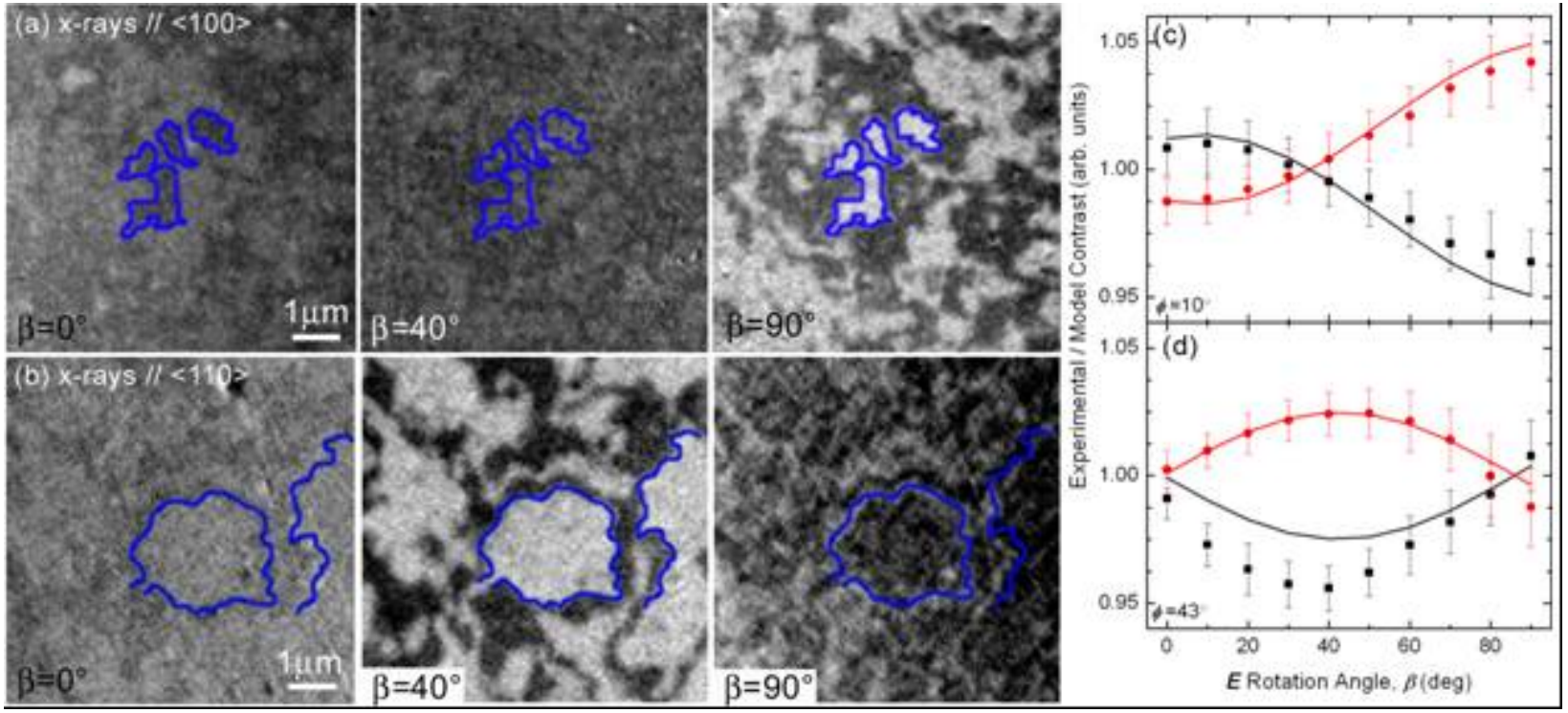
F. Nolting et al., Nature 2000

Angle Dependent XLD Contrast at Room Temperature

Xrays || <100>

LSMO is paramagnetic

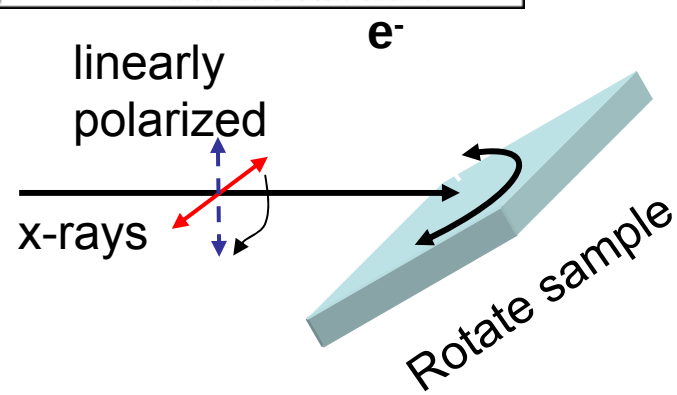
Experimental and simulated contrast



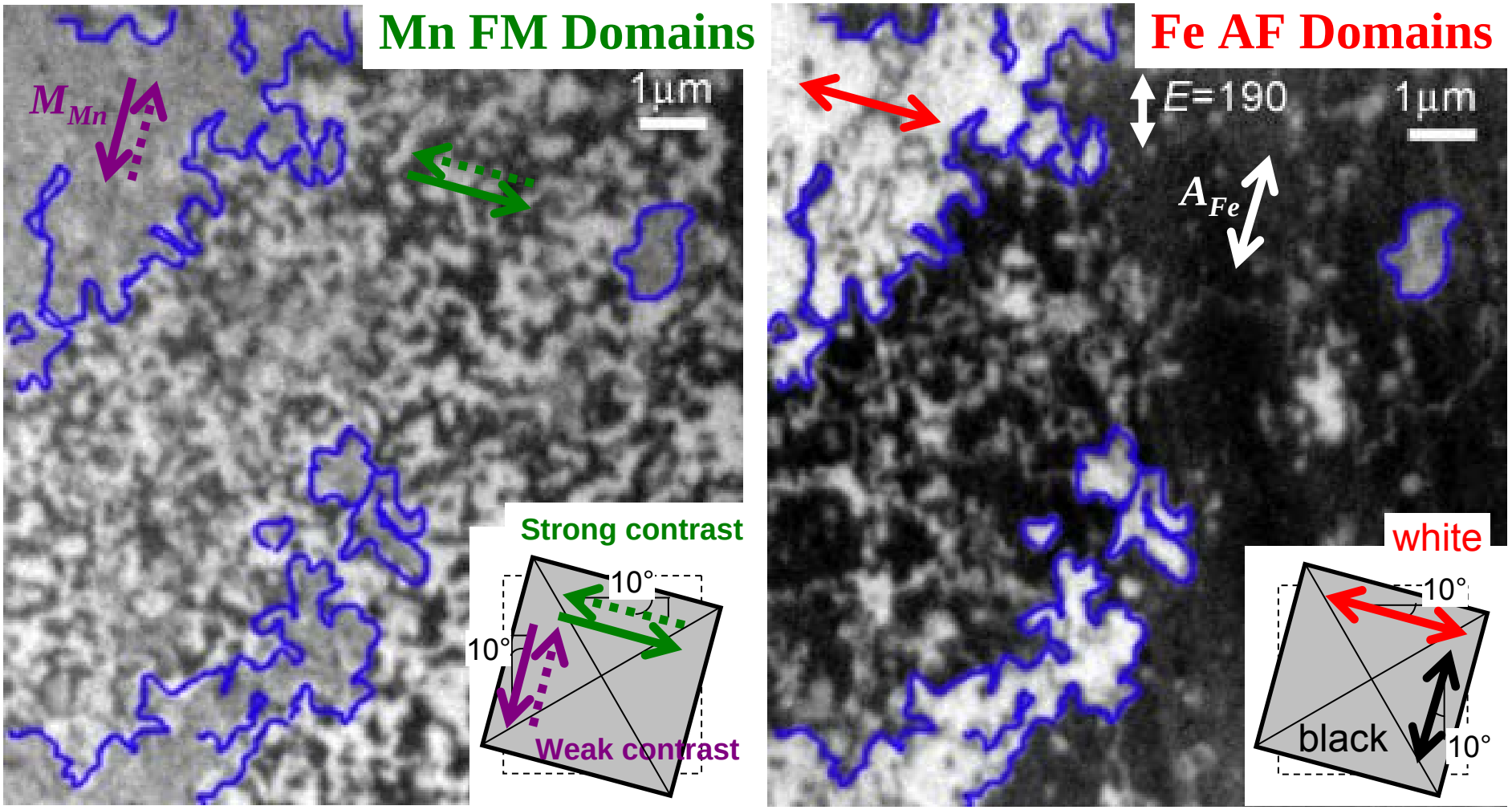
Xrays || <110>

LSFO is antiferromagnetic

AFM axis is along the in-plane <100> directions



Imaging Exchange coupling below T_c of LSMO



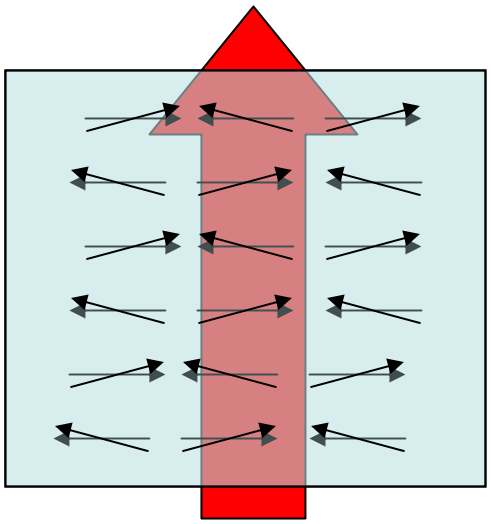
[6x6]10

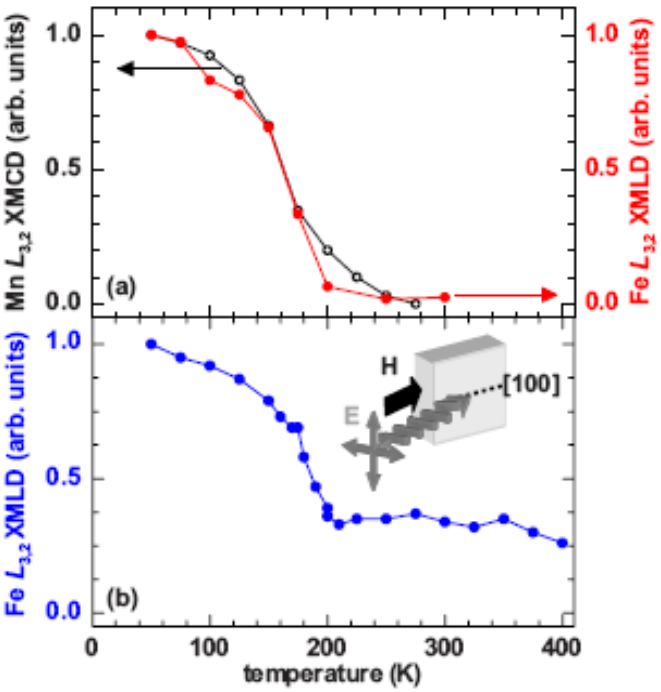
x-rays

T=38K

Regions with strong Mn contrast correlate to black Fe AFM domains
=> Spin-flop coupling

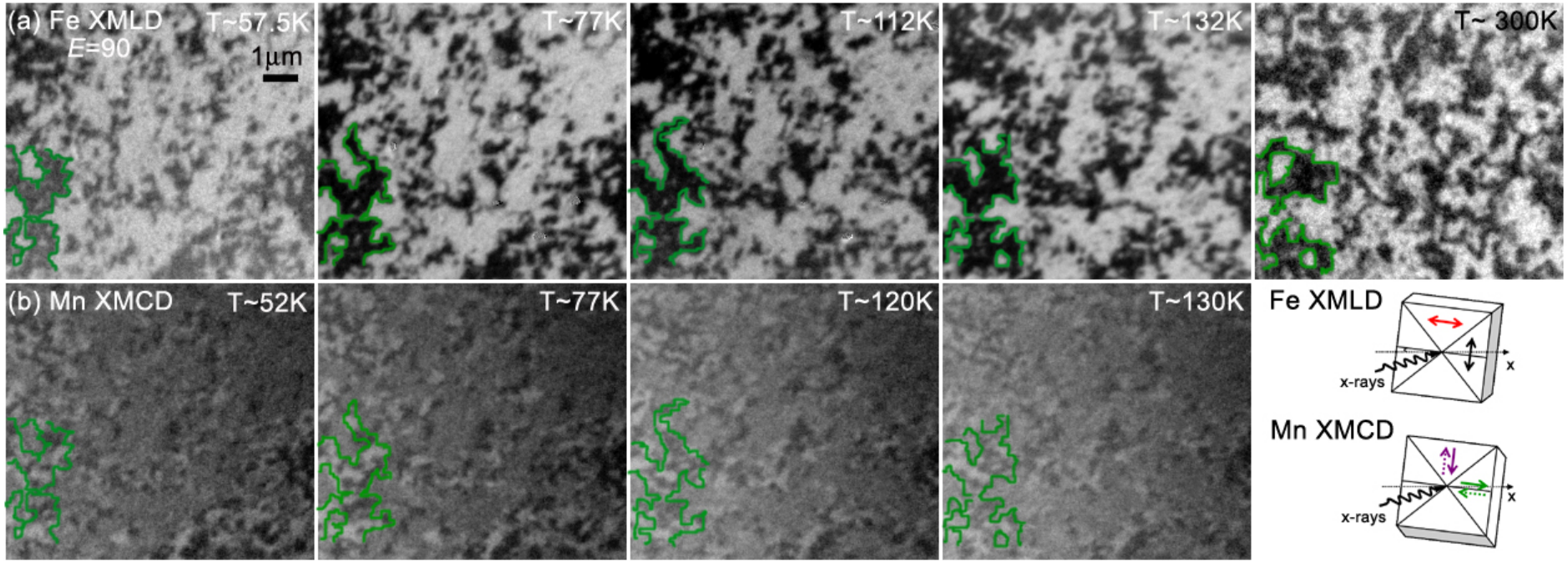
Spin Flop Coupling





AFM orders perpendicular to the field to minimize exchange energy

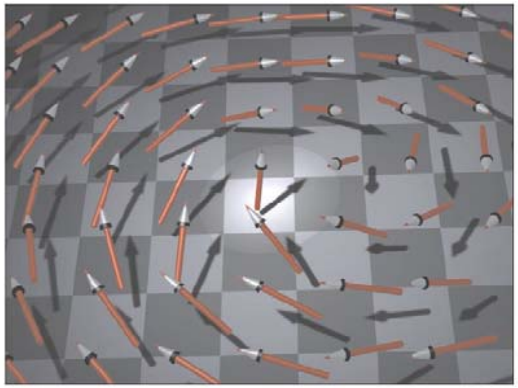
Magnetic Domain Formation in LSMO/LSFO multilayers

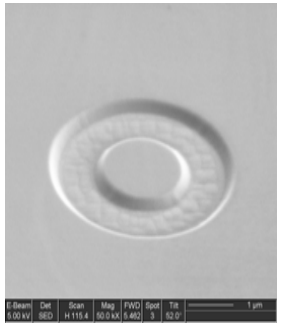


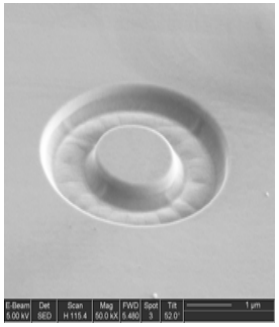
- Fe AFM are mobile while cooling through the LSMO Curie temperature.
- Crystal twin domains strongly pin AFM domains in thick single layers.

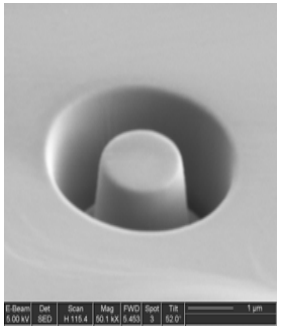
Direct Observation of Antiferromagnetic Vortices
J. Wu, Z.Q Qiu et al.

- **CoO/Fe(12 nm)/Ag(001) MBE grown sample**
- **Focused Iron Beam (FIB)**
  30keV Ga iron sputtering, ~10nm focus size
- **PEEM imaging**
  XMCD for Fe; XMLD for CoO



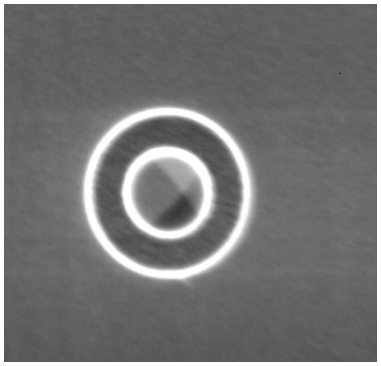




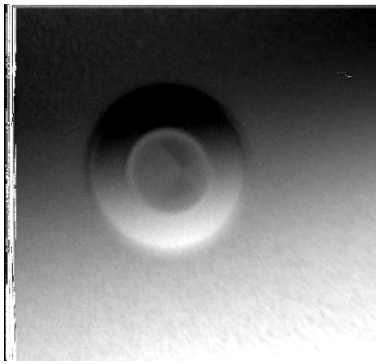


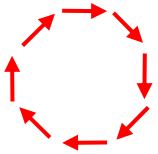
Two types of Antiferromagnetic Vortices

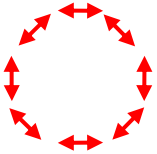
Fe XMCD



Ni XMLD

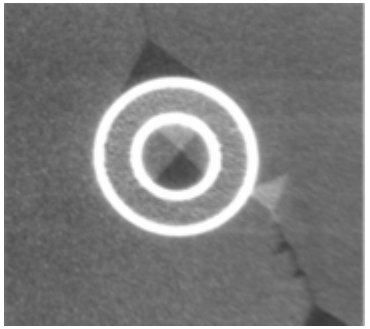


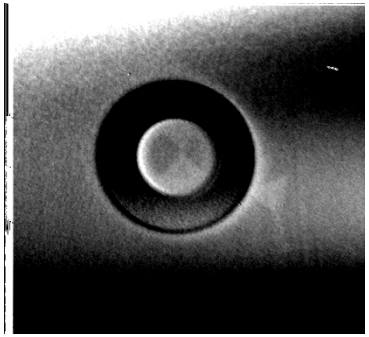


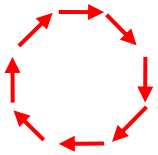


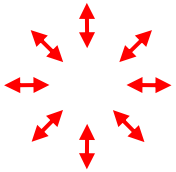
d_{NiO}=4ML; $\mathbf{S}_{Fe} // \mathbf{S}_{NiO}$

R=8μm





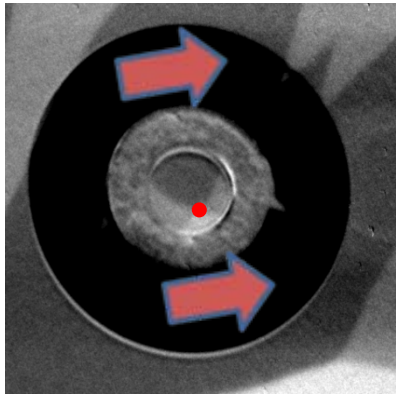




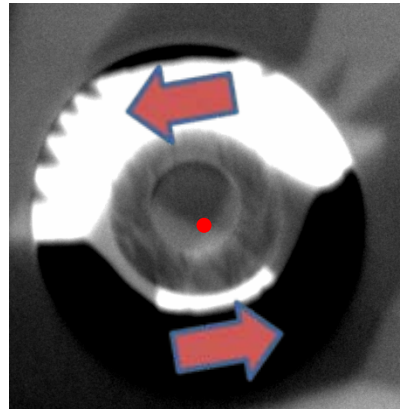
d_{NiO}=14ML; $\mathbf{S}_{Fe} \perp \mathbf{S}_{NiO}$

Imprint & Interaction Between FM and AFM vortex

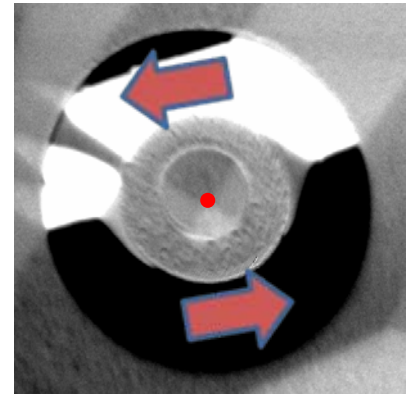
Fe
XMCD



Field cooling

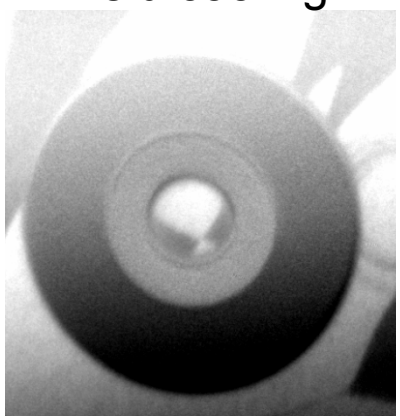


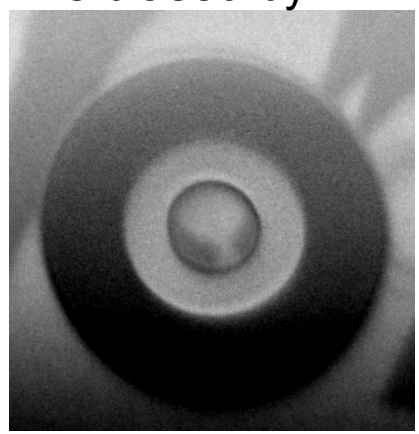
FM is biased by AFM

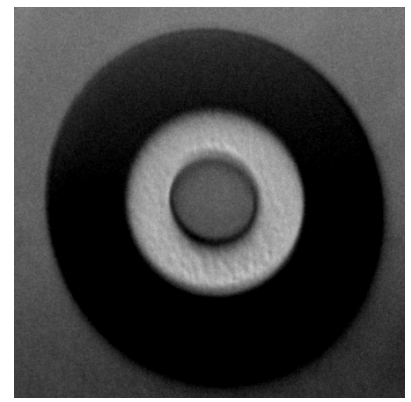


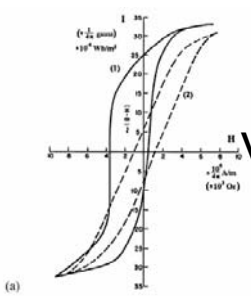
FM relaxes T_N

Co
XMLD









150 K

Vortex core shifted
by dipole field

150 K

Vortex held
by exchange bias field

300 K

Vortex core moves
towards center after
$T>T_N$

Summary

PEEM sample holder with field capability and cooling down to 30 K

Spin flop coupling observed in LSFO/LSMO epitaxial multilayers

Antiferromagnetic vortices generated by field cooling in contact with a ferromagnet.

Acknowledgments:

A. Doran, A.T Young, LBNL – PEEM-3

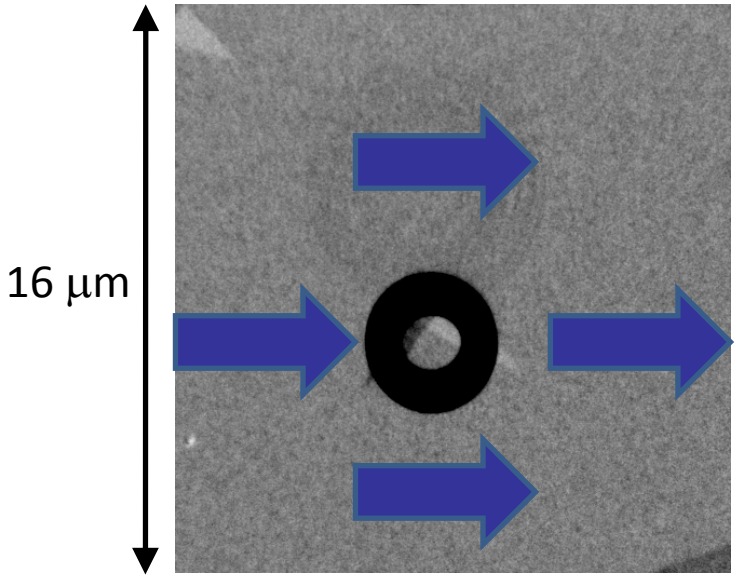
J. Wu, Z.Q Qiu, UC Berkeley – Antiferromagnetic Vortices

F. Yang, Y. Takamura, UC Davis – Spin Flop Coupling

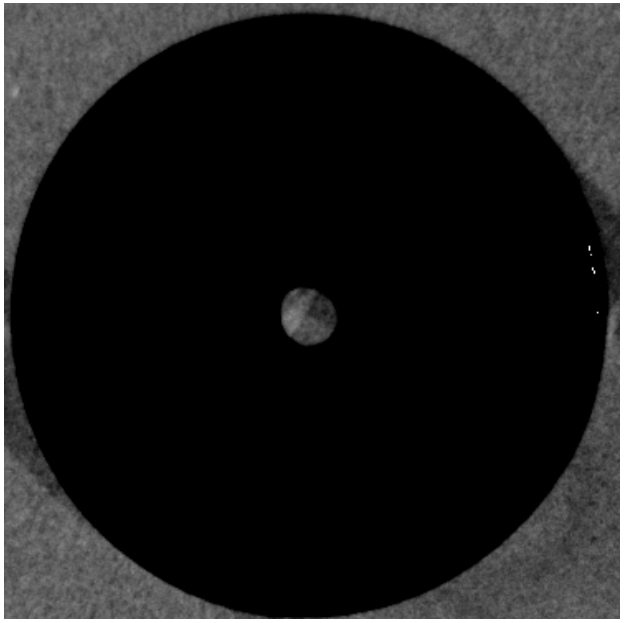
Not shown:
M. Burkhardt, S. Hossein, SLAC – LSMO domain structure at Tc

H. He, R. Ramesh, UC Berkeley – Magnetism of $BiFeO_3$

Static Vortex Displacement Using A Dipole Field



vortex center biased



vortex centered

At the center of the disk, the effective field is proportional to 1/r.

For the left image, the field is ~100 Oe.