Magnetic circular dichroism imaging of Fe(100) in threshold PEEM

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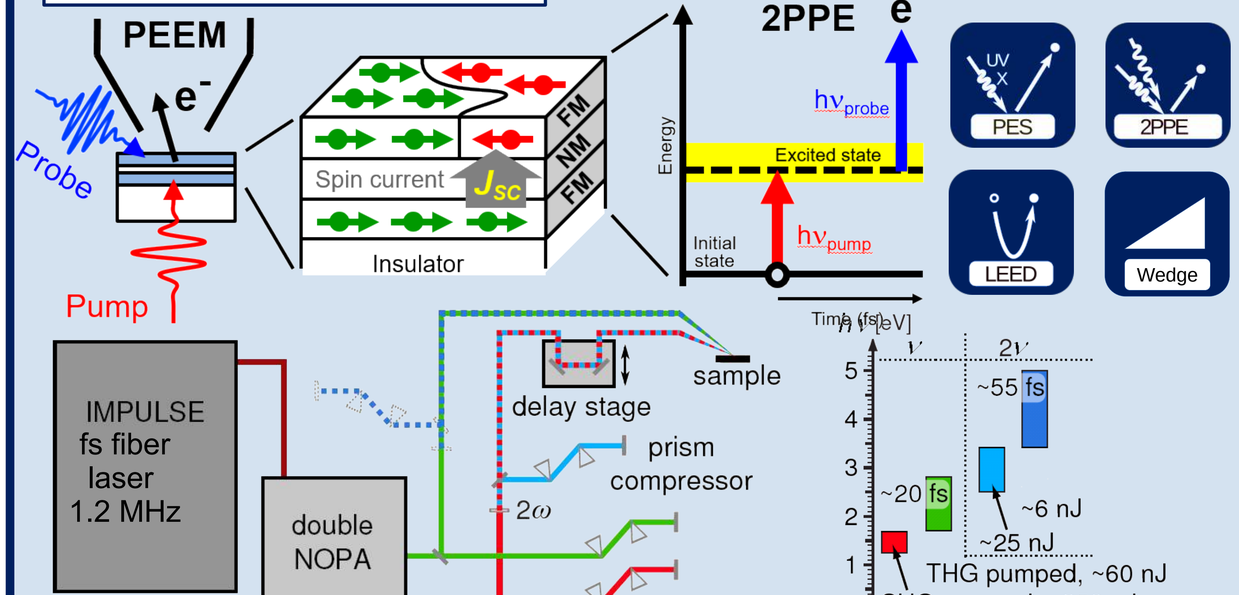
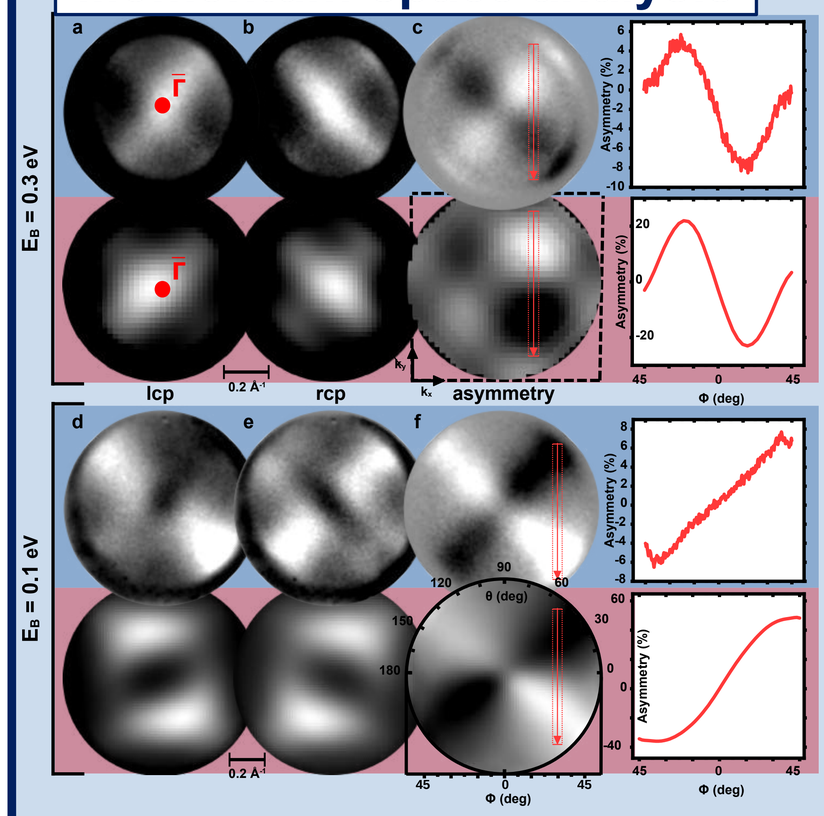
PEEM / ARPES



[1,2]

- IMPULSE, Clark MXR fiber laser, 1.23 MHz, 20W
- Double noncollinear optical parametric amplifier (double NOPA)

Momentum-space analysis

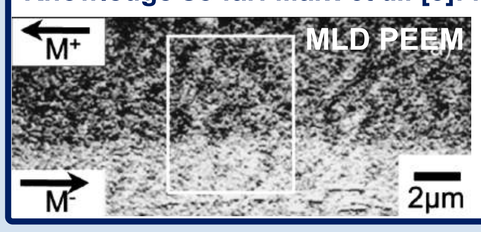


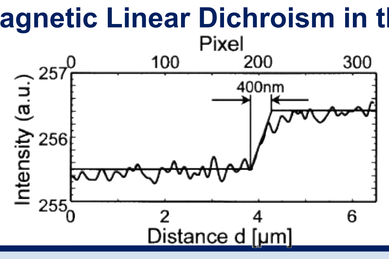
Energy resolved k-space imaging:

- Comparison between measurement (top row) and omni calculations (bottom row)
- Measured on one domain only → electrons stem from homogeneously magnetized area
- Switch of asymmetry sign at E_B = 0.2 eV
- Asymmetry in off-axis configuration orders of magnitude larger than in integrated mode
  → **drastic improvements of sensitivity of the technique**

Magnetometry via Normal Incidence

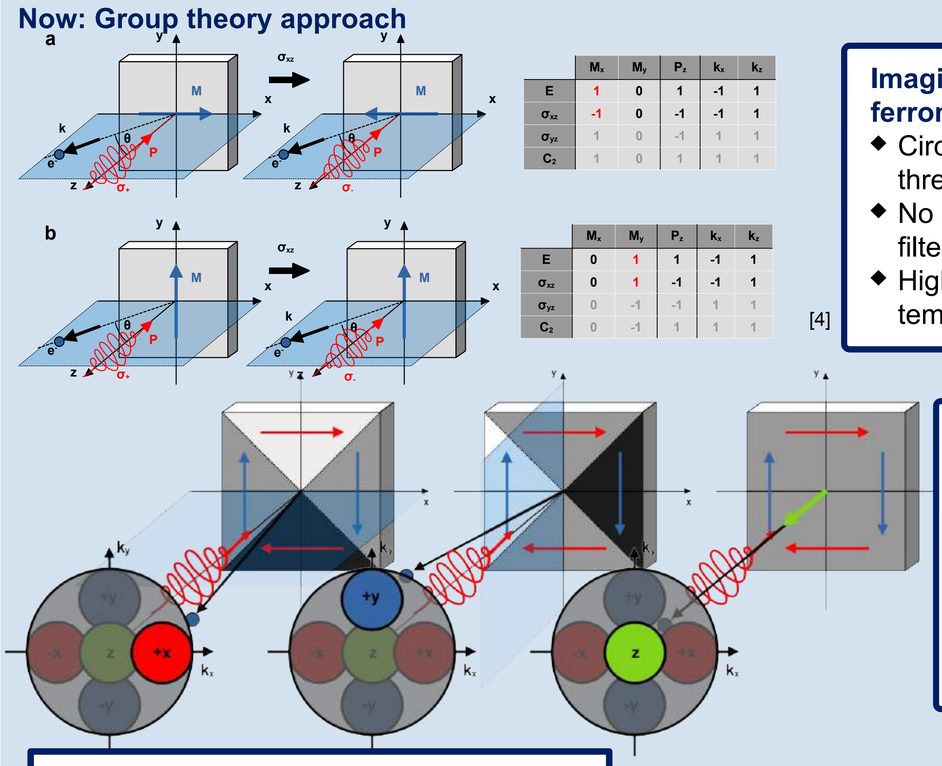
Knowledge so far: Marx *et al.* [3]: Magnetic Linear Dichroism in threshold PEEM





- Asymmetry: 0.37%
- Explained by Kerr-like mechanism

Now: Group theory approach



	M_x	M_y	P_z	k_x	k_z
E	1	0	1	-1	1
σ_{xz}	-1	0	-1	-1	1
σ_{yz}	1	0	-1	1	1
C_2	1	0	1	1	1

	M_x	M_y	P_z	k_x	k_z
E	0	1	1	-1	1
σ_{xz}	0	1	-1	-1	1
σ_{yz}	0	-1	-1	1	1
C_2	0	-1	1	1	1

[4]

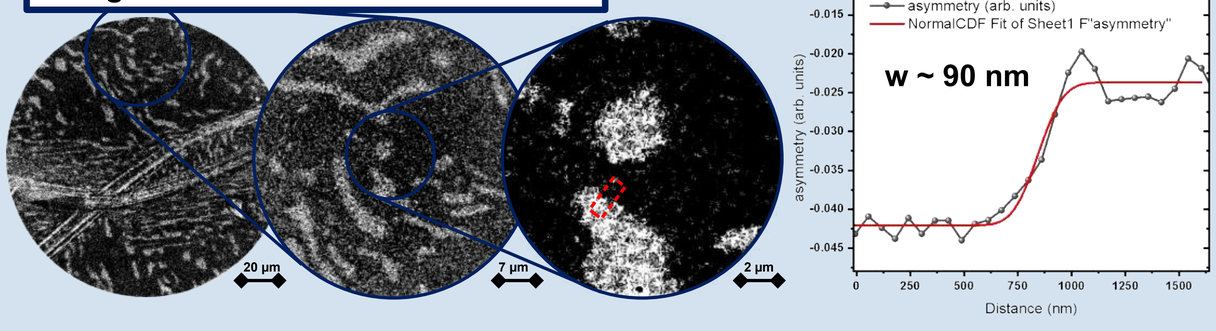
$$A = \frac{I_{lcp} - I_{rcp}}{I_{lcp} + I_{rcp}}$$

Imaging of ferromagnetic domains:

- Circular Dichroism threshold imaging
- No x-ray source or spin filtering needed
- High spatial and temporal resolution

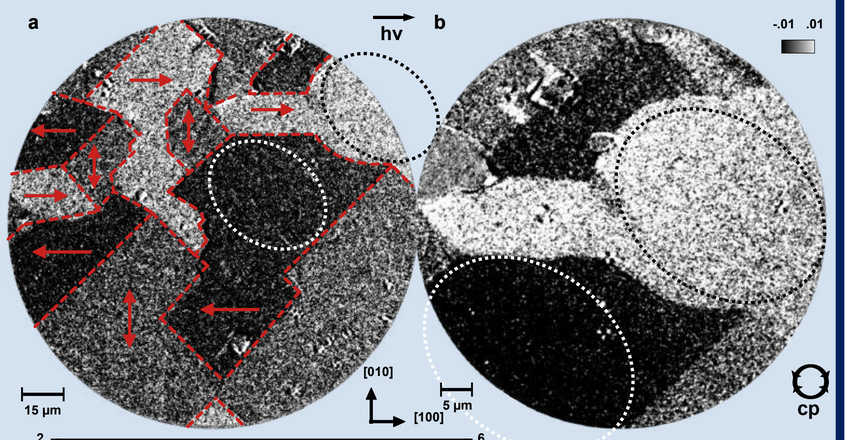
Normal Incidence
High symmetry of NI config. allows "magnetometronic" distinction between in-plane and out-of-plane components of **M**

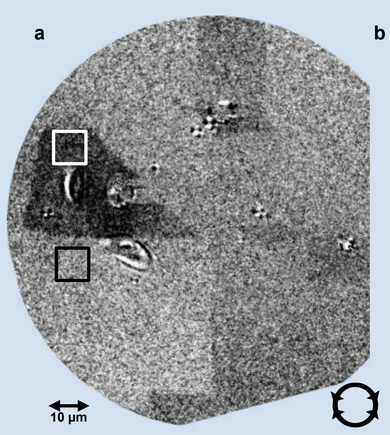
Magnetic lateral resolution < 90 nm

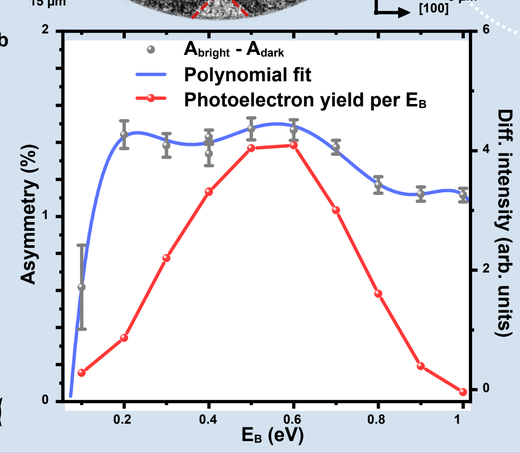


In-plane domains:

- Distinction between collinear magnetization directions
- Domain walls along high symmetry directions or pinned to defects
- Large domains allow for k-space imaging



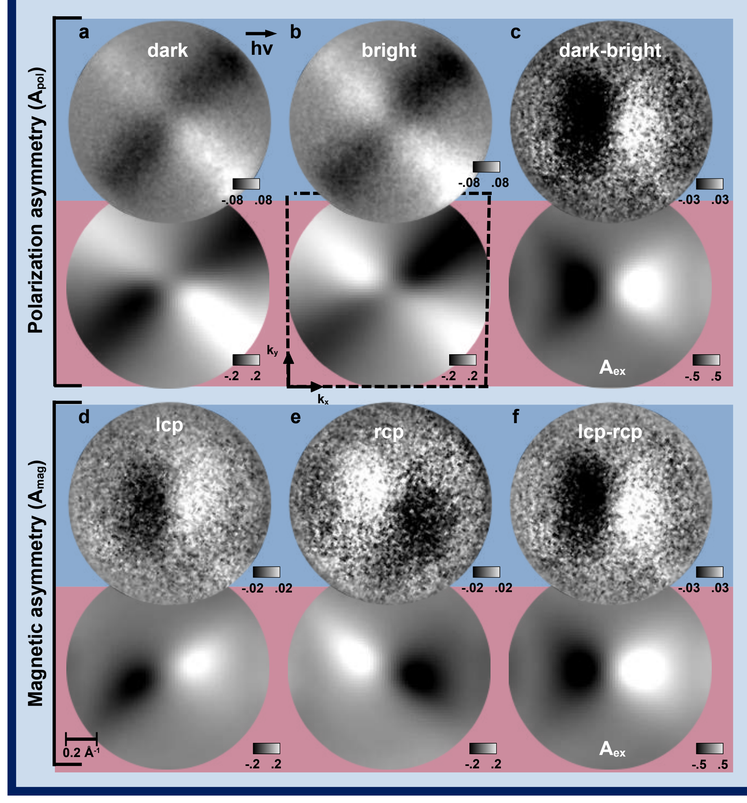




Energy scans:

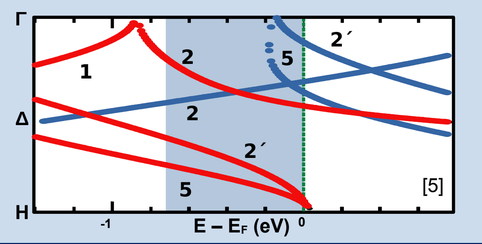
- Max. asymmetry of ~ 1.5%
- Constant asymmetry from E_F to E_B = 1 eV
- Best figure of merit at E_B = 0.6 eV

Polarization / Magnetic asymmetry



Distinction between spin-orbit (SO) and exchange contribution:

- A_{pol} representing SO contribution (top)
- A_{mag} representing magnetic contribution (bottom)
  → distinctly different asymmetry in k-space
- Difference gives A_{ex}
- Explained by switch from majority to minority band photoemission channel
  → **further theoretical data needed**



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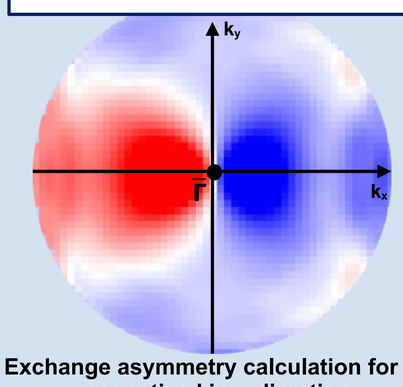
Off-axis threshold laser-PEEM

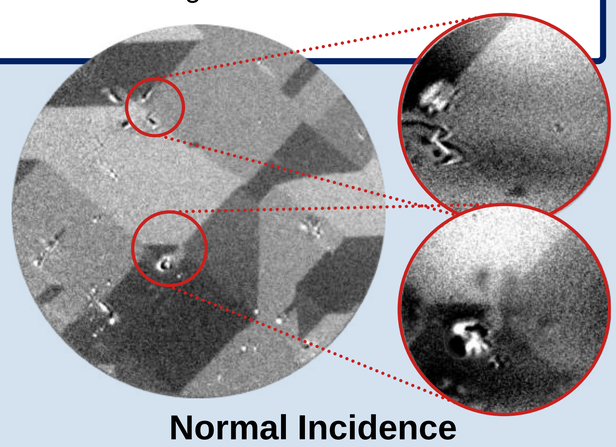


Exchange asymmetry calculation for Fe magnetized in x-direction (NI excitation, hv = 5.2 eV, E_B = 0.4 eV)

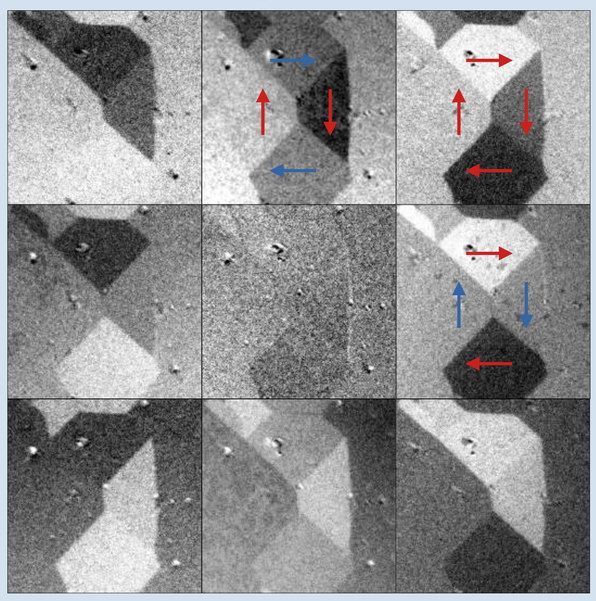
Increased magnetic contrast

- Placing an aperture in the back-focal plane in the region of maximum exchange asymmetry gives increase in magnetic contrast in real space (up to 6% total)
  → **This enables laser measurements!**
- Additionally, choosing the right k-space region, the sensitivity to different magnetization directions can be tuned

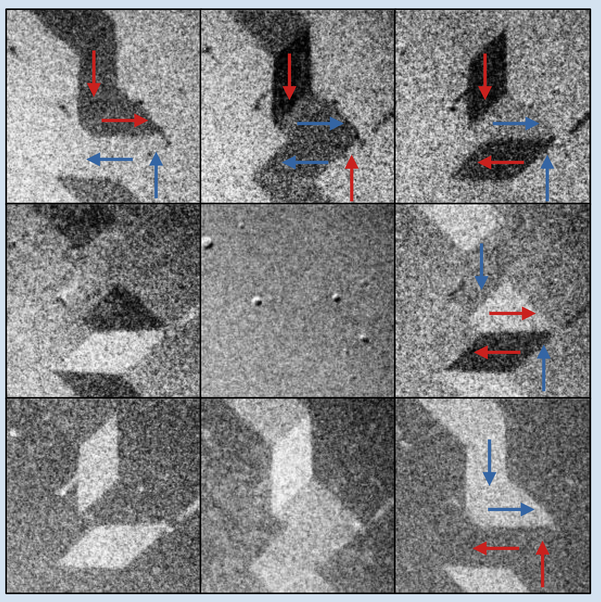
The symmetry argument explained on the left only gives an intuitive answer for high-symmetry, "on-axis" configurations! If you measure off-axis, a lot more is going on!



Grazing Incidence



Normal Incidence



Summary

- **Threshold MCD imaging of in-plane and out-of-plane domain at nm spatial resolution**
- **Consequent application of group theory approach correctly describes photoemission**
- **Drastically increased asymmetries in off-axis geometry → laser measurements**
- **Deconvolute spin-orbit and exchange contribution via different asymmetry modes**

References

[1] K. Gillmeister, PhD thesis, MLU Halle-Wittenberg (2014).
[2] A. Höfer *et al.,* IBM Journal of Research and Development **55,** 4 (2011).
[3] G. Marx *et al.,* Phys. Rev. Lett. **84**, 5888 (2000).
[4] R. Feder, J. Henk, in Spin-Orbit-Influenced Spectroscopies of Magnetic Solids, 466,85–104 (1996).
[5] F. Giebels *et al.,* Phys. Rev. B, **84**, 16, 165421 (2011).