ALS-Workshop Oct. 04 on
Magnetic Nanostructures, Interfaces, and New Materials:
Theory, Experiment and Applications

# Soft X-Ray Magneto-Optics of Lanthanides

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# Outline

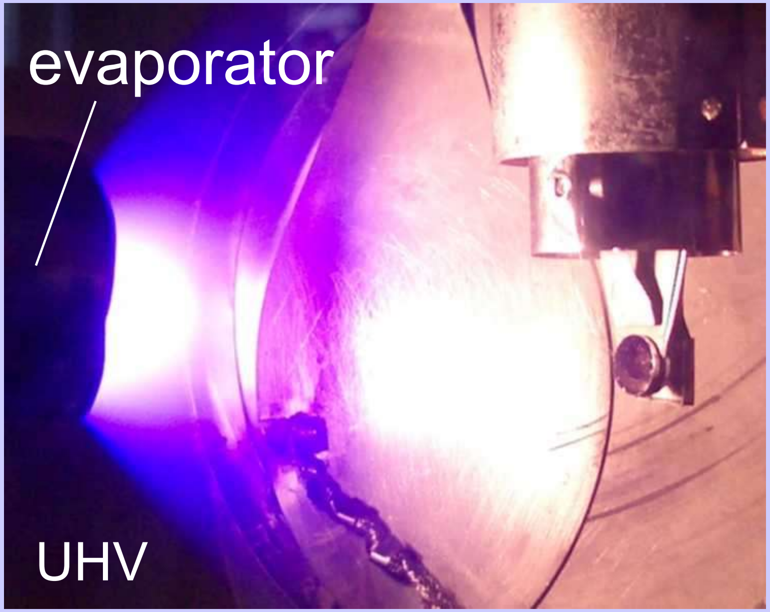
1. Sample preparation
2. Quantifying MO constants
3. Interlayer coupling (T)

# 1. Sample preparation

Hetero-epitaxial film growth on crystalline substrates

- metal vapor deposition in UHV ($10^{-11}$mbar)

⋮




Dy plasma during evaporator cleaning

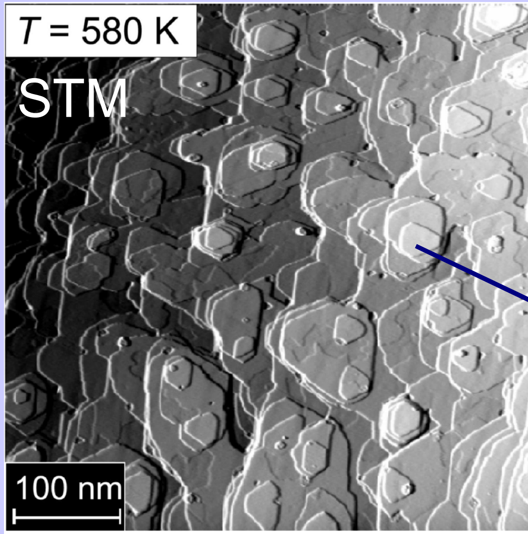
- growth of “multi”-layers
- cap layers (Al, Ti, ..) for ex-situ studies

*K. Starke: Magnetic Dichroism in Core-Level Photoemission (Springer, Berlin, Heidelberg, 2000)*

# 1. Sample preparation: Tb film on W(110)

## 40-layer Tb film morphology changes by annealing

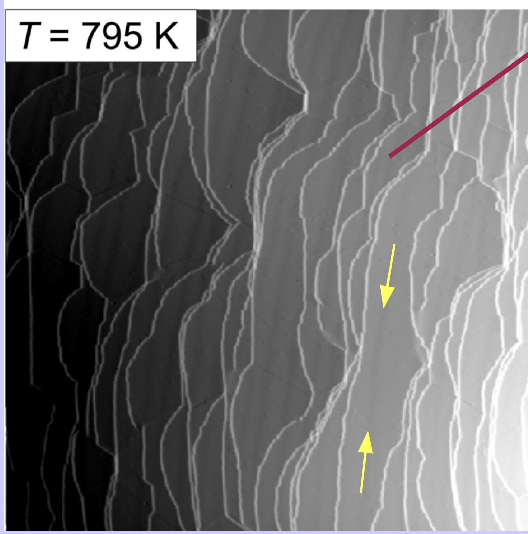
grown at 300 K



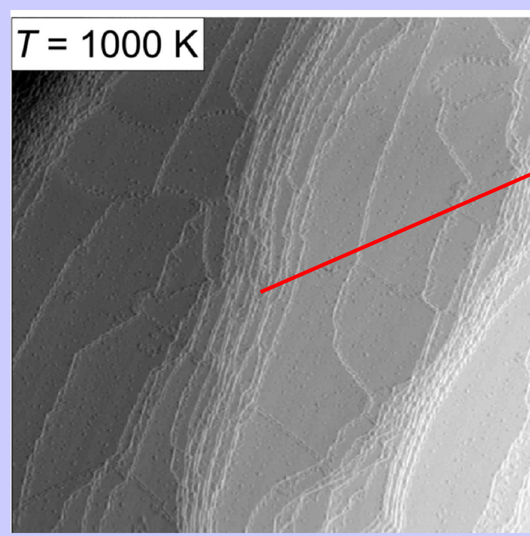

Poisson height distribution

small islands, hcp stacking

annealed at 795 K




30..50 nm wide terraces
monatomic steps




1 nA, 0.6 mV

annealed at 1000 K

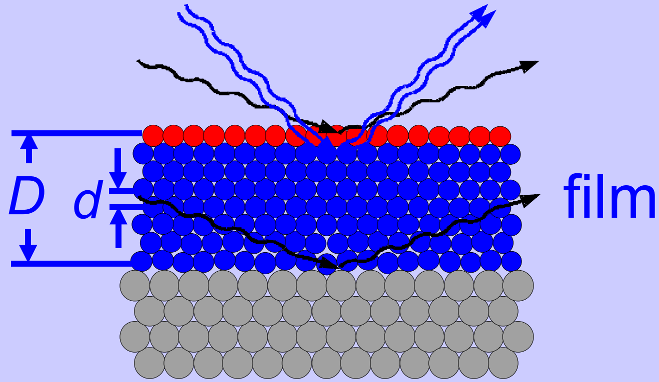
step bunching

- extended **AF phase** observed
  $T_N$ - $T_C$ = **17 K**

F. Heigl *et al.,* subm. to Phys. Rev. B (2004)

# 1. Sample preparation

*In situ* X-ray diffraction

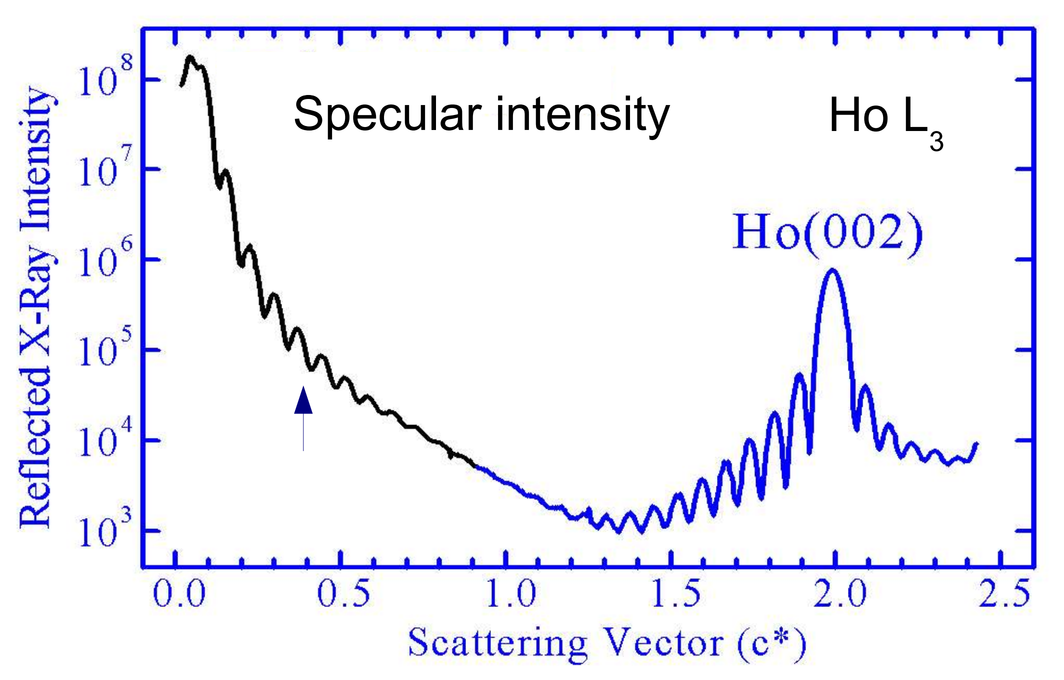



7.7 nm Ho(0001) film on W(110)

- thickness and roughness
- strain, layer relaxation

Specular reflection at fixed c*

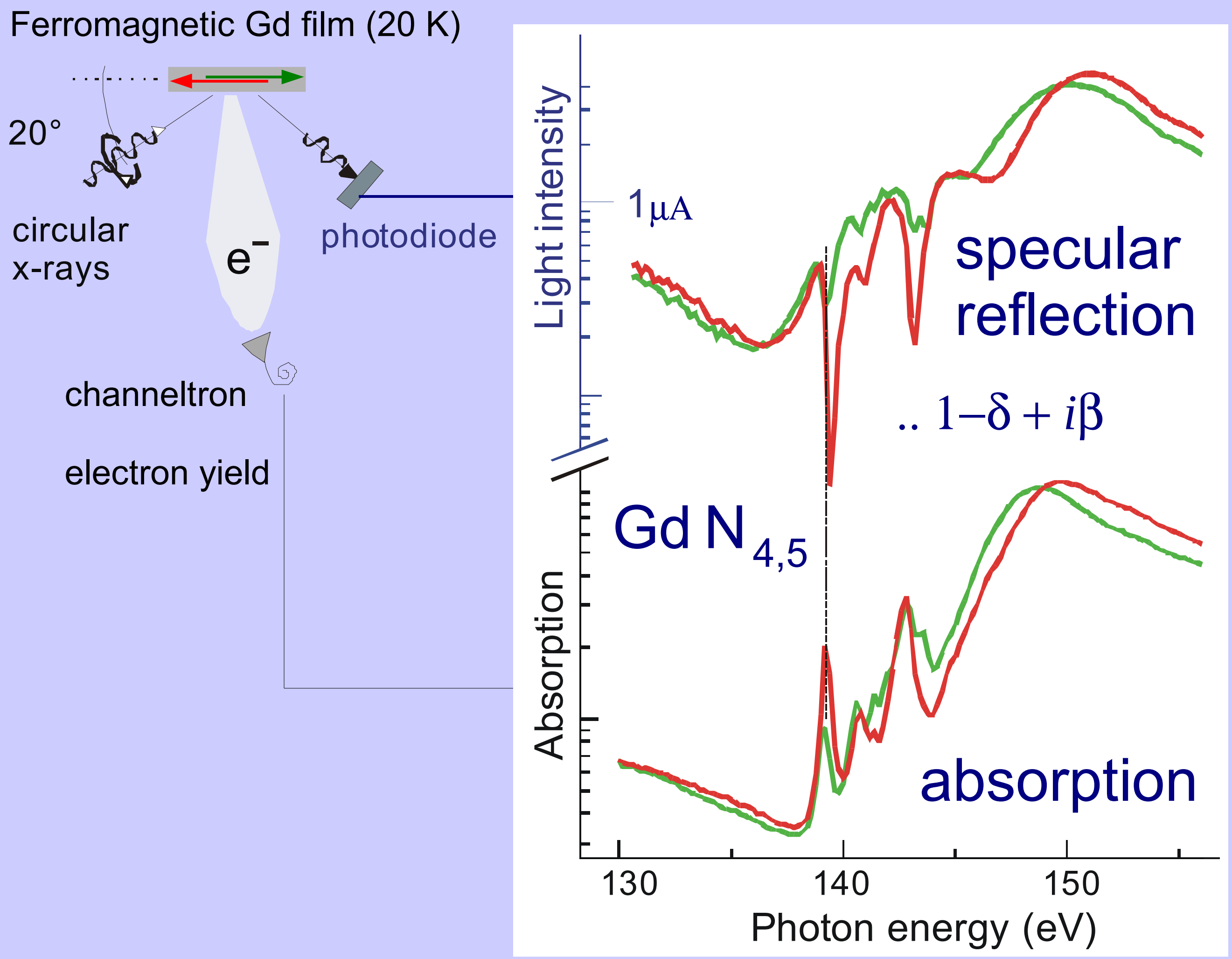
- intensity oscillations during growth allows in situ characterization




*E. Weschke, C. Schüssler-Langeheine et al., PRL 79, 3954 (1997)*

# 2. Quantifying MO constants

## Gd 4d-4f "Giant Resonance" 100..200 eV

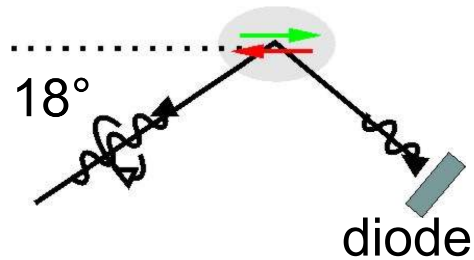



- Fano profiles
- 0.01 .. 1 μA specularly reflected photocurrent
- use experimental imaginary part β to calculate *n* via KKT

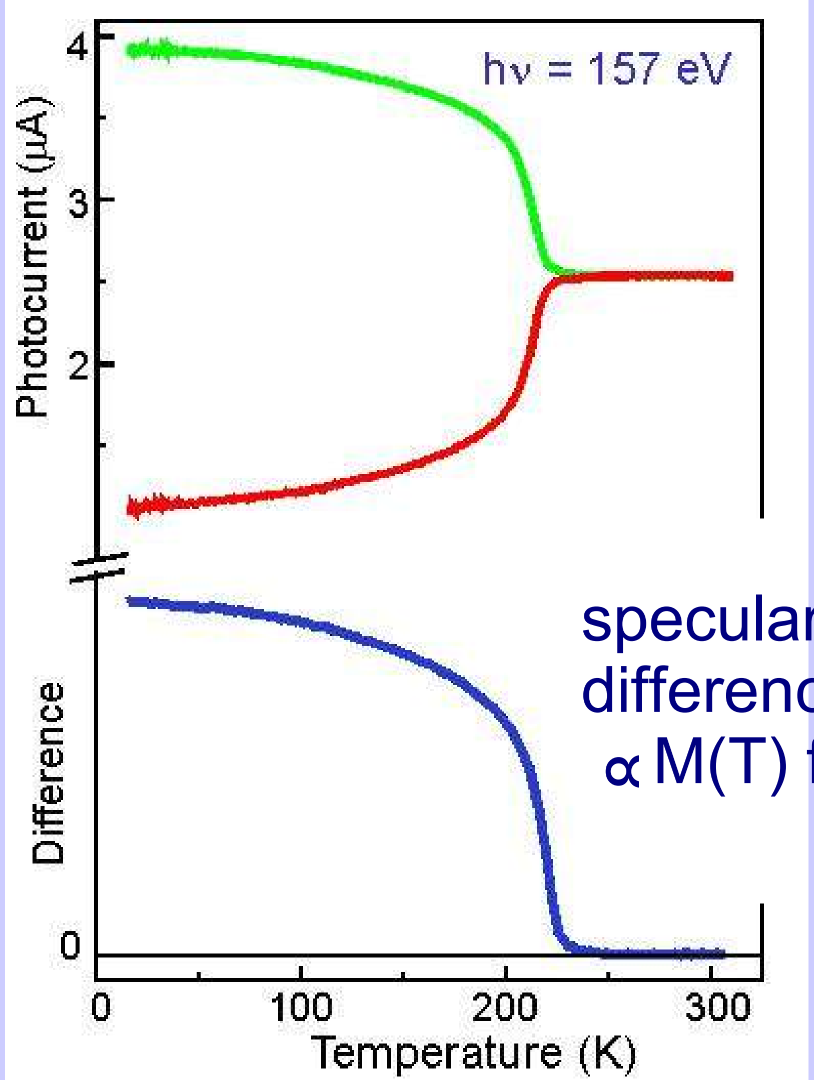
*K. Starke et al., Phys. Rev. B 55, 2672 (1997); Phys. Rev. Lett. 86, 3415 (2001)*

# 2. Quantifying MO constants

## Temperature dependent specular reflection from Tb film




Thick Tb film (8 nm)
hν fixed to
Tb 4d-4f resonance

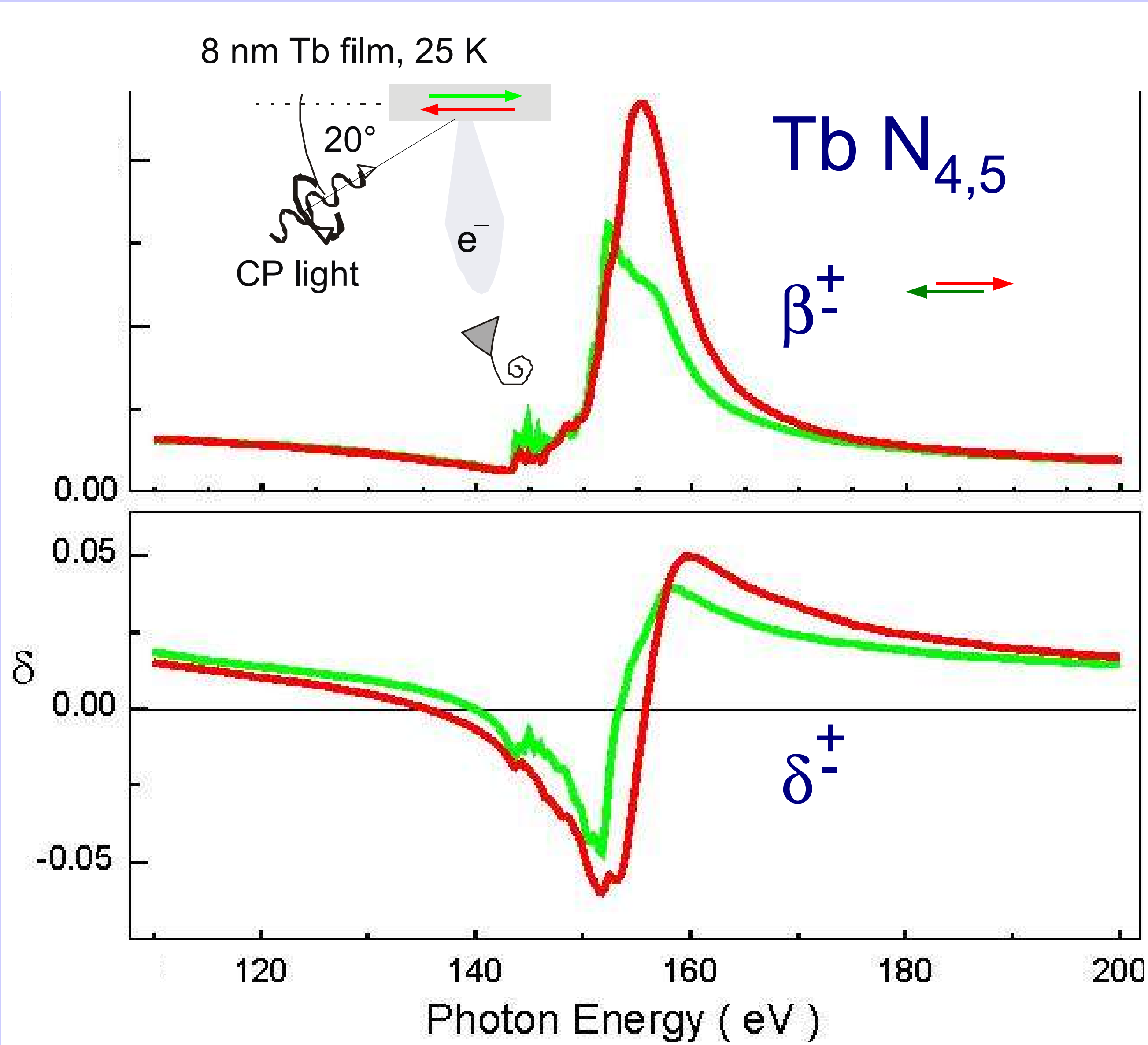



specular reflection difference
$\propto$ M(T) for 'thick' film

*K. Starke et al.,*
*Phys. Rev. Lett. 86, 3415 (2001)*

# 2. Quantifying MO constants

## Experimental absorption, dispersion via KKT: Tb $N_{4,5}$



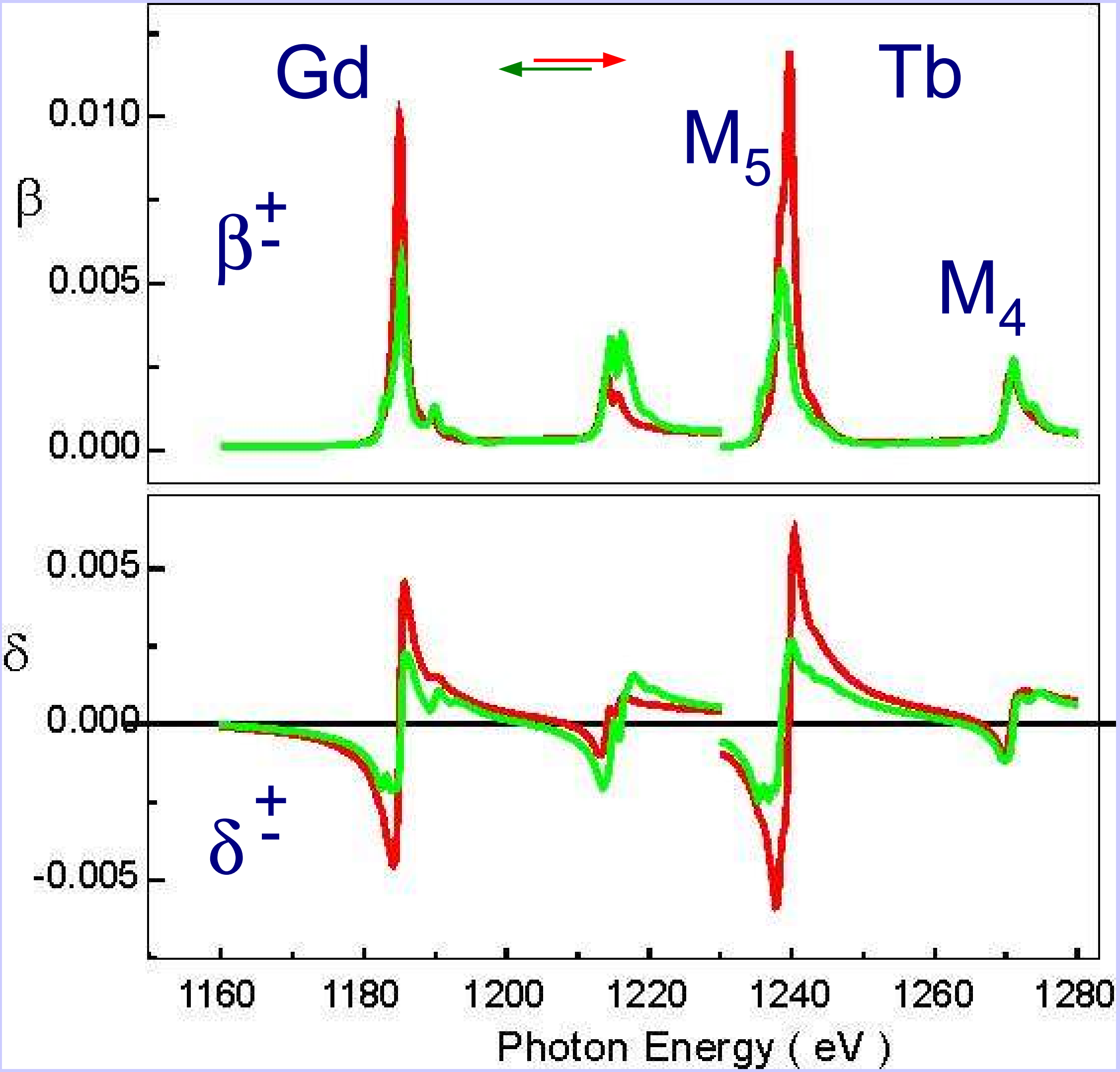

- wide hν range to <u>match</u> experimental β to data tables (Henke)

$$n = 1 - \delta + i\beta$$

- δ <u>calculated</u> via KKT using imaginary part β
- option: δ and β via KKT from reflectivity spectrum

# 2. Quantifying MO constants

Determination of MO constants at Gd and Tb $M_{4,5}$



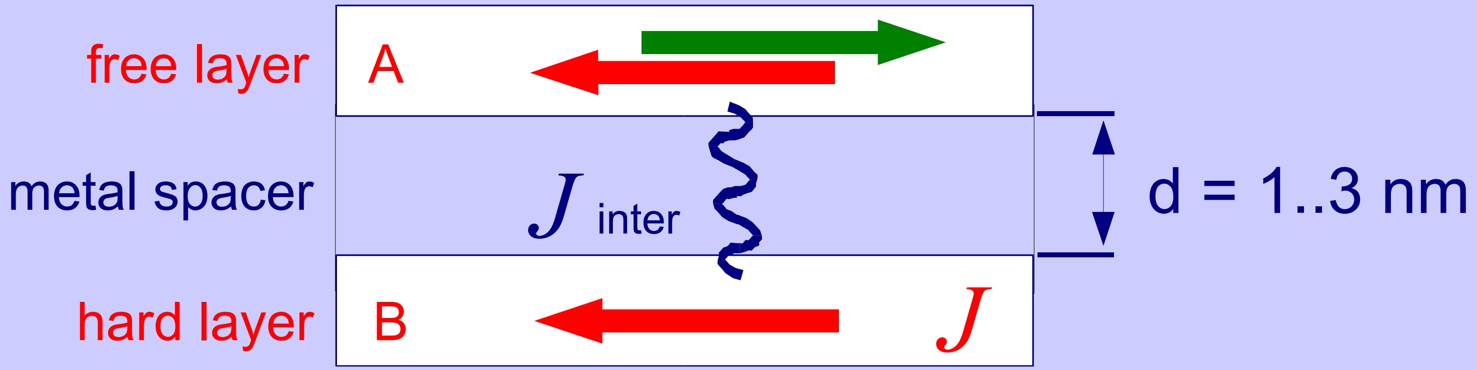

- high element specificity
- apply to exchange coupled magnetic layers

J.E. Prieto et al., Phys. Rev. B 66, 172408 (2002); ibid. 68, 134453 (2003)

# 3. Interlayer coupling (T)

mediated by spin dependent QWS

$$2k_{\perp}d + \phi_A + \phi_B = 2\pi\, n$$




Take rare earth metals for A, B:

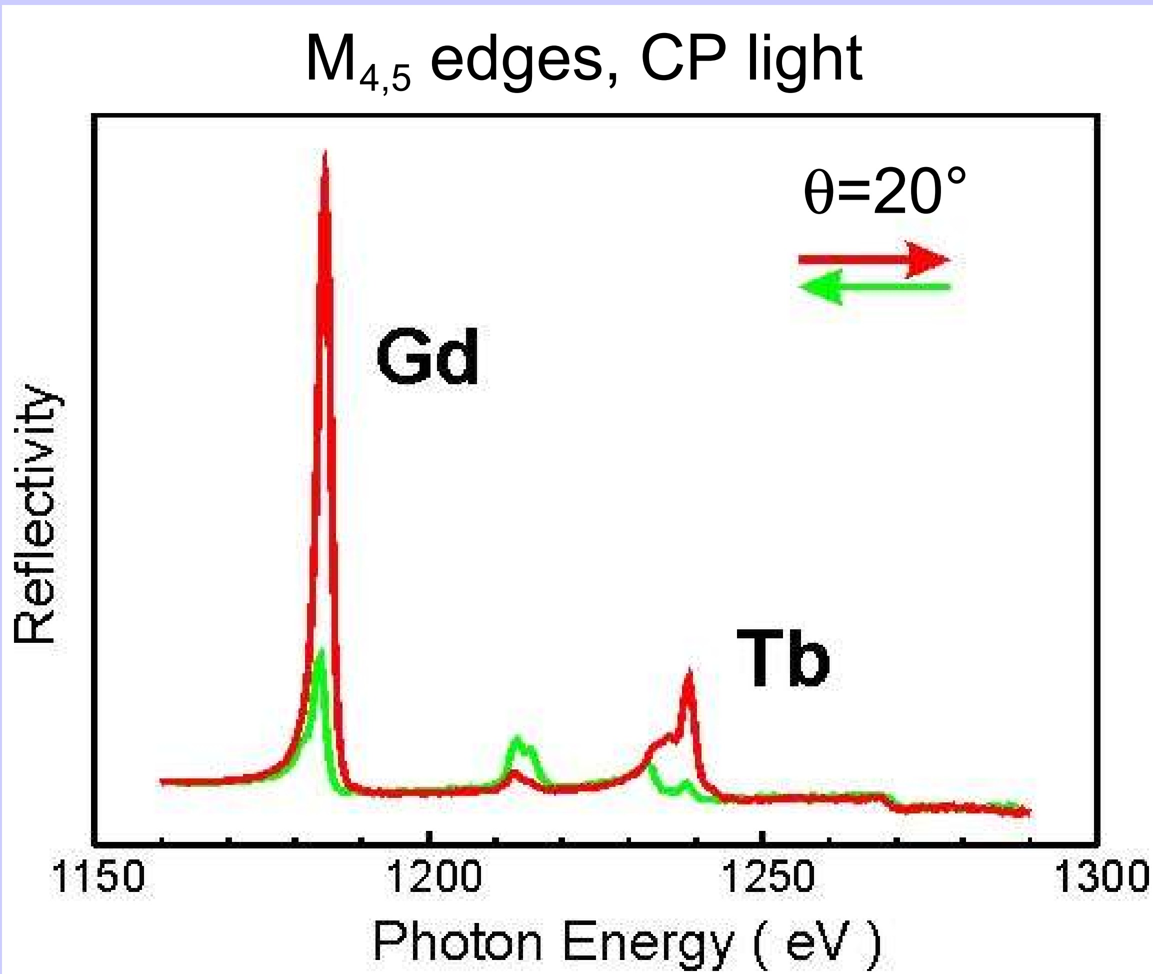
- indirect 4f-5d coupling (RKKY)
- $J \approx J_{inter}$

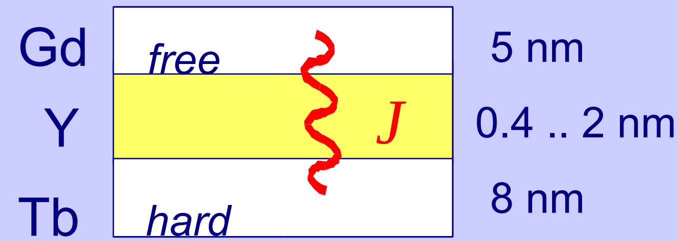
Different elements

- individual hysteresis for A, B

# 3. Interlayer exchange coupling

## Specular reflection at $M_{4,5}$ off a Gd/Y/Tb trilayer

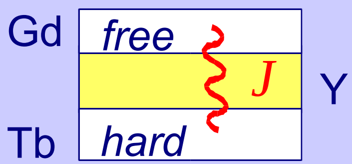


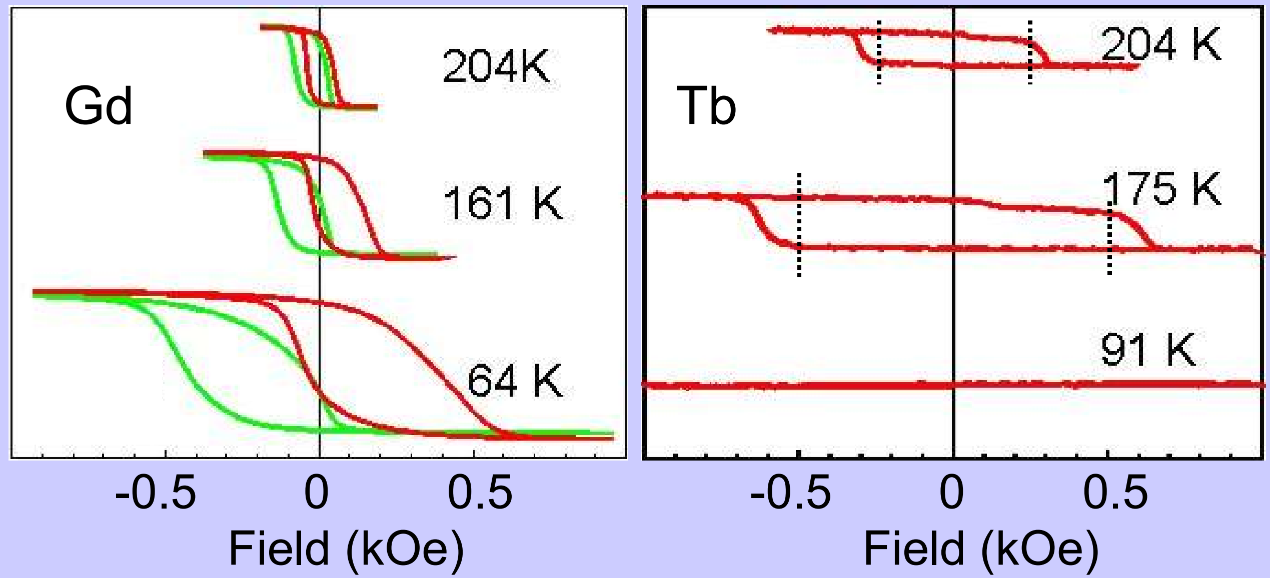



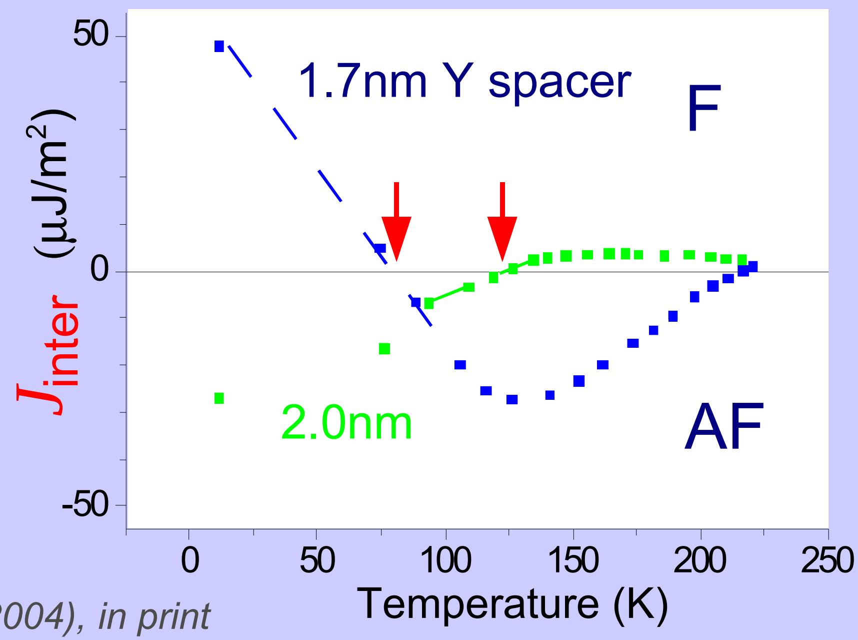

- 0.1 .. 10 nA specular photocurrent

*J. E. Prieto et al., Phys. Rev. B 68, 134453 (2003)*

# 3. Interlayer coupling (T)




crossover from **F** to **AF** interlayer exchange coupling with temperature

*J. E. Prieto et al.,*
*Appl. Phys. A 79 (2004), in print*

# Summary

Sample preparation

Quantifying MO constants

Interlayer coupling (T)

# Suggestions for soft x-ray scattering beamline

- Sample preparation (transfer system ?)
- Access to sample
- 500..1500 eV (include very soft?)
- 10..20 K with .. 0.5 T

# Collaborations

| | |
|---|---|
| J. E. Prieto | UA Madrid |
| E. Rotenberg | ALS |
| S. Blügel | FZ Jülich |
| M. Bode | U Hamburg |
| P. Carra | ESRF |
| J. Feldhaus | DESY |
| H. A. Dürr | BESSY |
| A. Scholl | LBNL |
| .. | |

# Students & Coworkers

Oleg Krupin

Jose Prieto*

Kristian Döbrich

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