

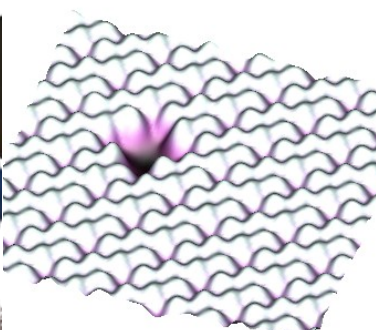
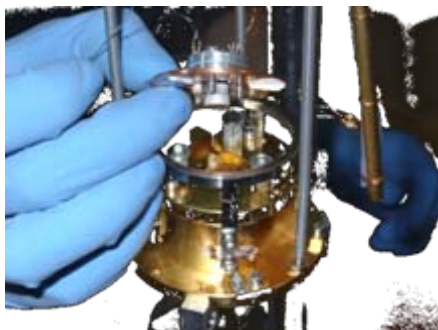
Single-ion magnetic anisotropy and magnetic resonance phenomena

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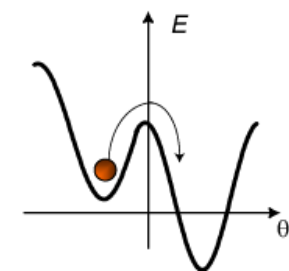
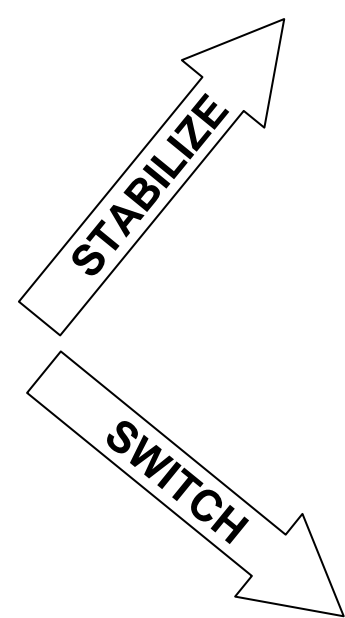
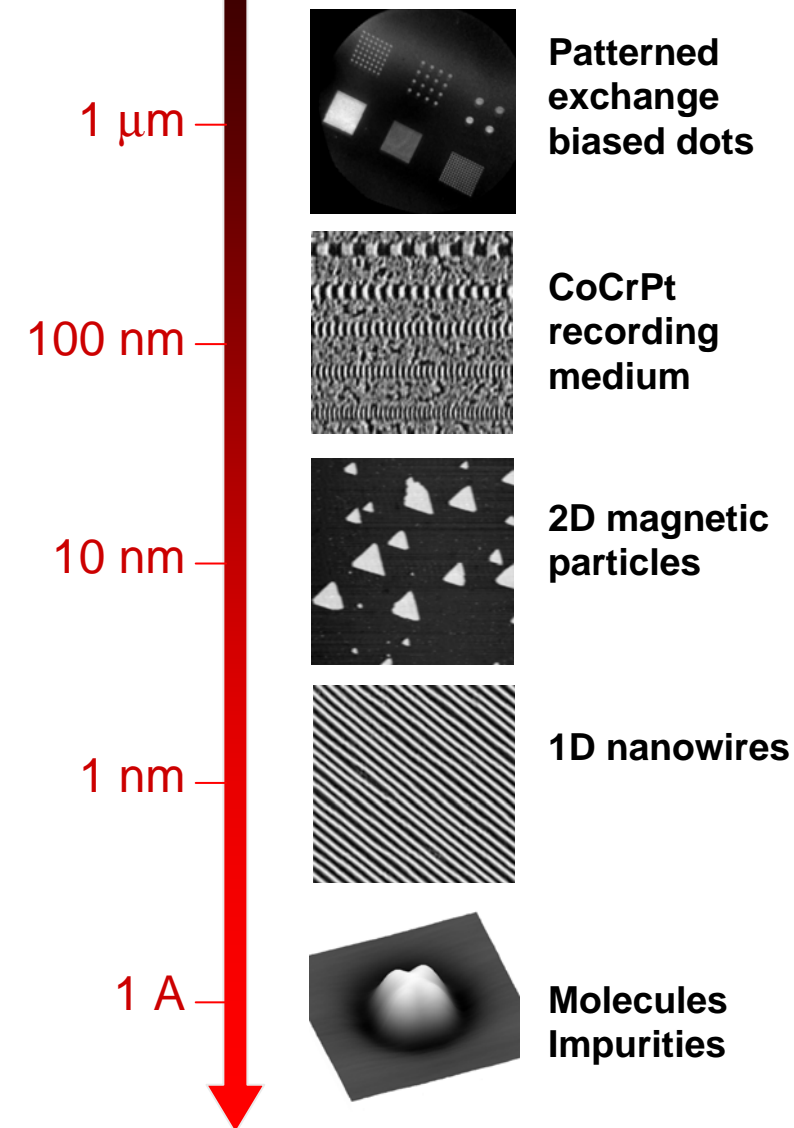
Barcelona, Spain

www.cin2.es



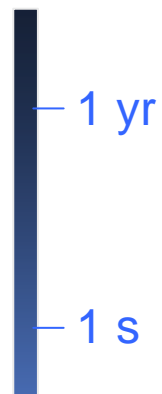
Nanoscale magnetism

Space



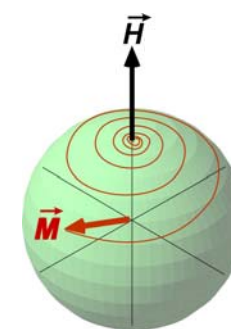
Magnetic relaxation

Time



1 yr

1 s



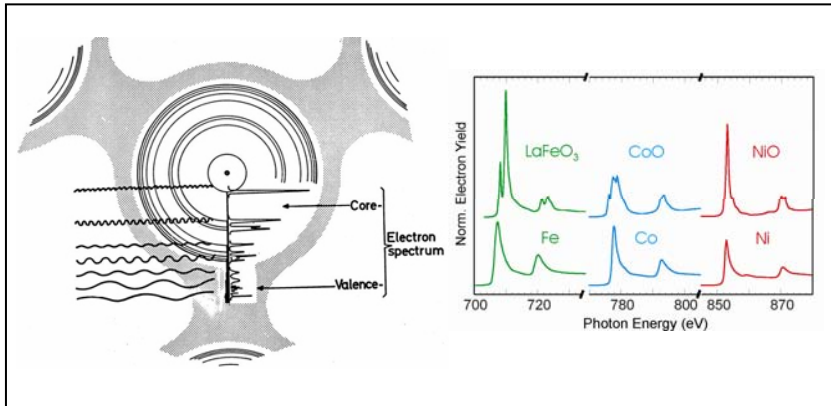
Magnetization reversal
Precession



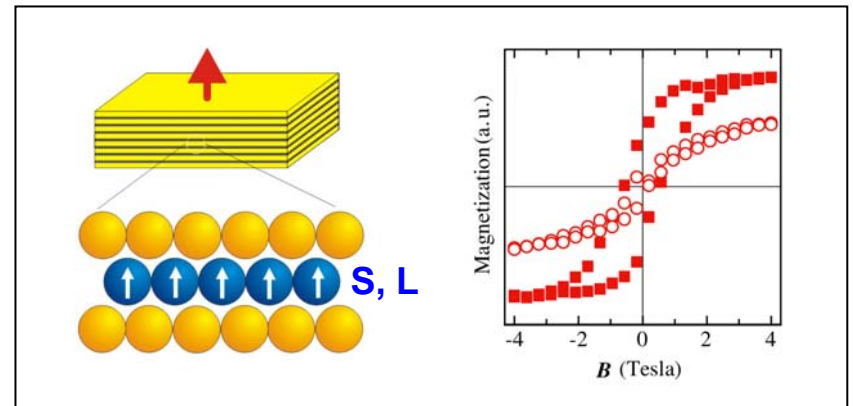
1 ns

"But, soft! What light ... "

Electronic Structure and Bonding
- where are the electrons -

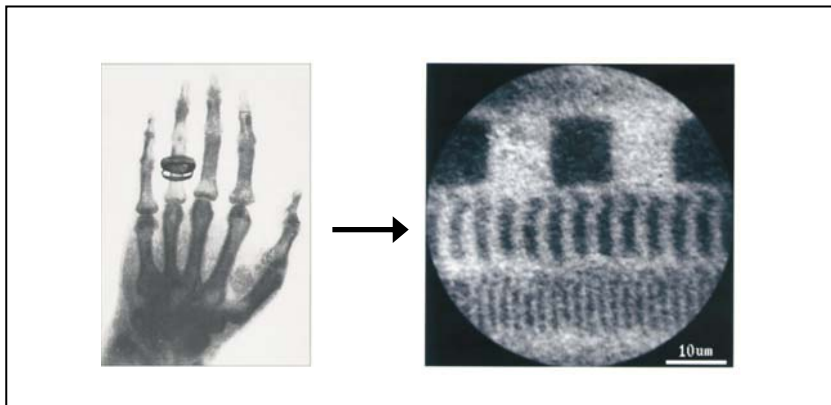


Magnetic Structure and Properties
- where are the spins -



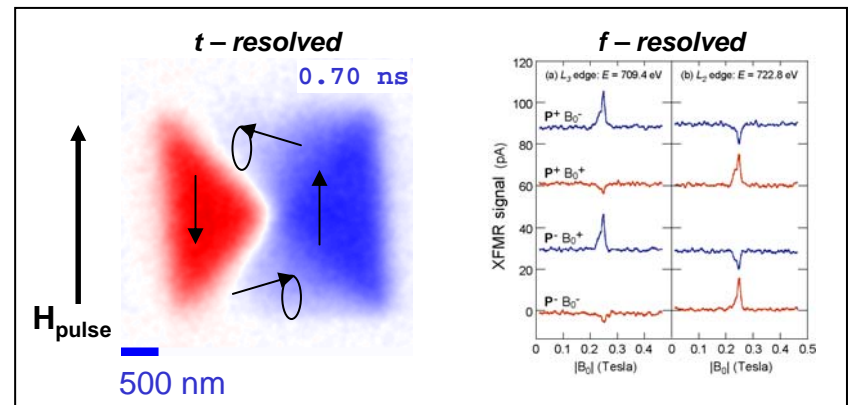
Imaging

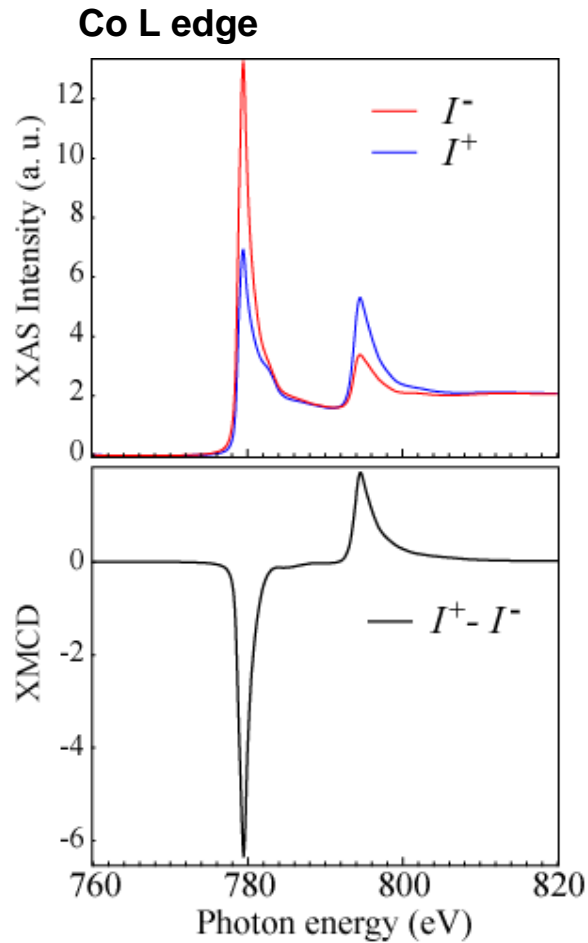
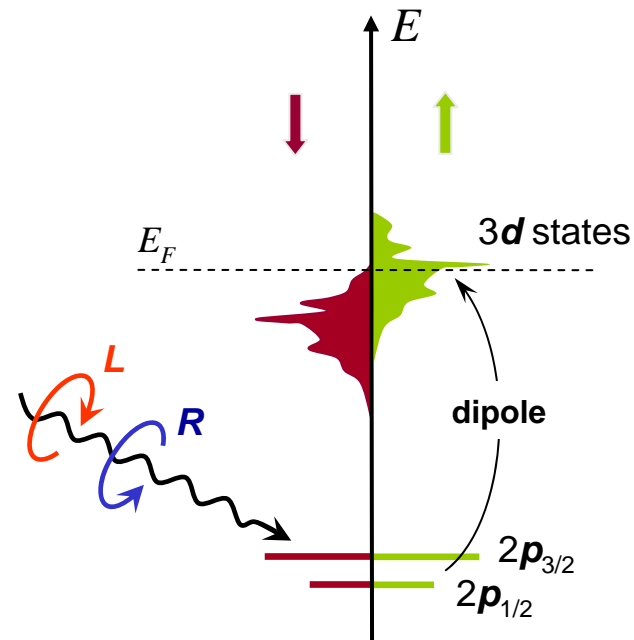
- elemental and magnetic contrast -



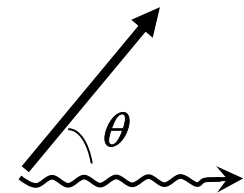
Magnetodynamics

- detecting spin and orbital motion -





$$I_{XMCD} \propto M \cdot \cos \theta$$



Sum Rules: XMCD intensity \rightarrow spin and orbital moment of electronic ground state

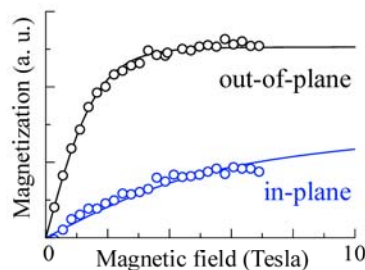
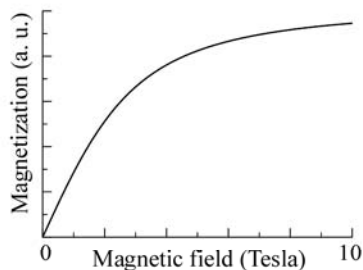
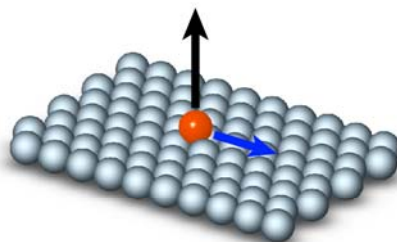
Thole *et al.*, PRL **68**, 1943 (1992);
Carra, *et al.*, PRL **70**, 694 (1993).

Onset of magnetic anisotropy in individual atoms: Co₁/Pt(111)

isotropic:
free magnetic atom



anisotropic:
magnetic atom on a surface



Factors that determine the magnetic anisotropy:

Angular dependence

- site symmetry

Magnitude

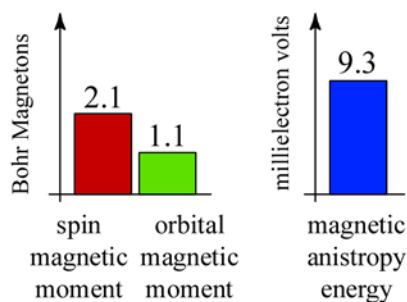
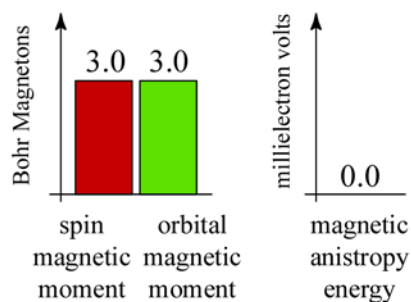
- 3d bandwidth

- orbital moment

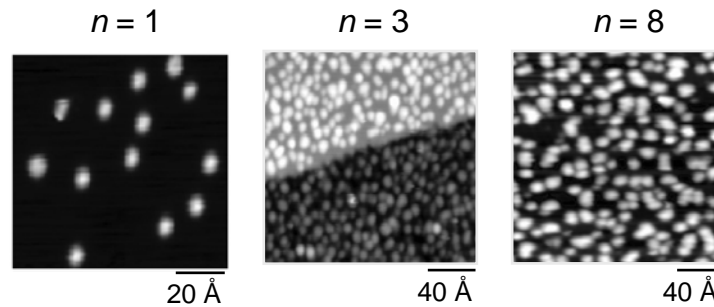
- spin-orbit coupling

K depends on the atomic coordination:

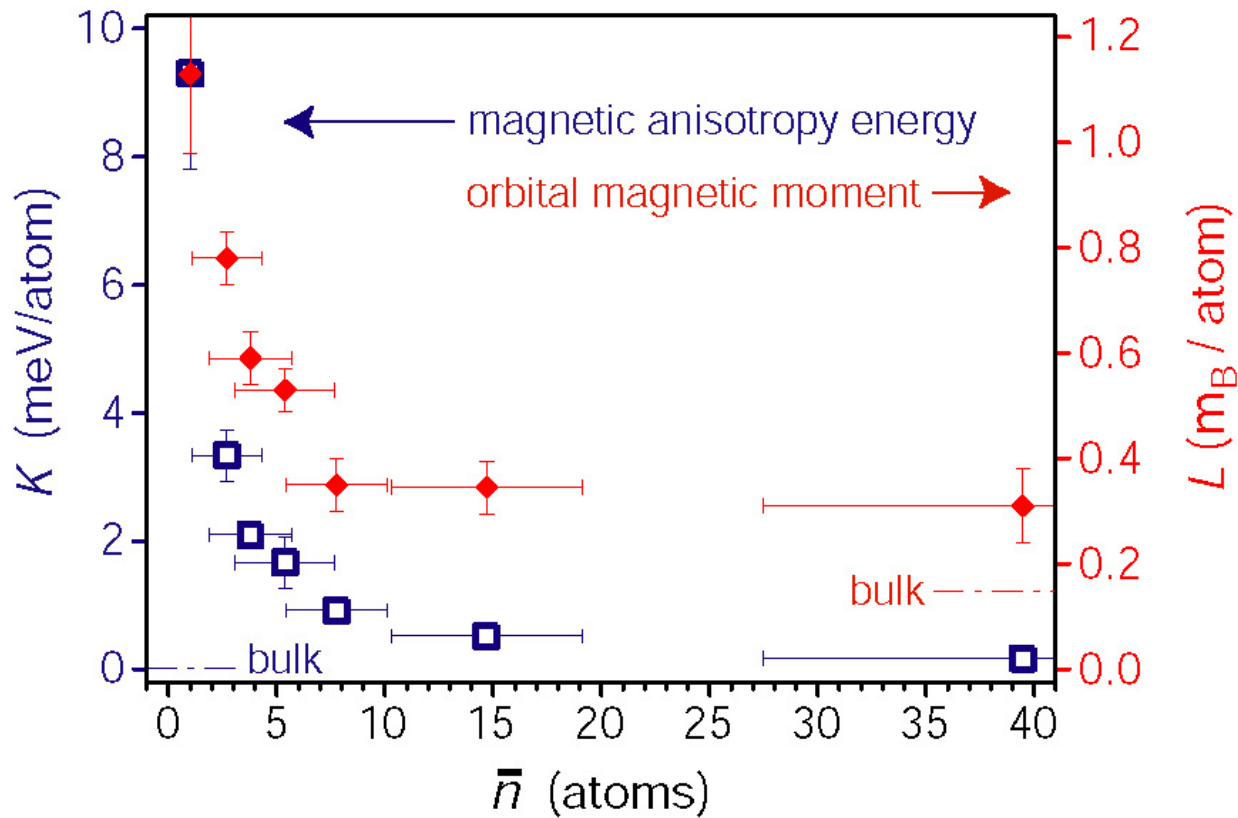
$$K_{\text{Co}_1/\text{Pt}} = 200 K_{\text{Co bulk}}$$

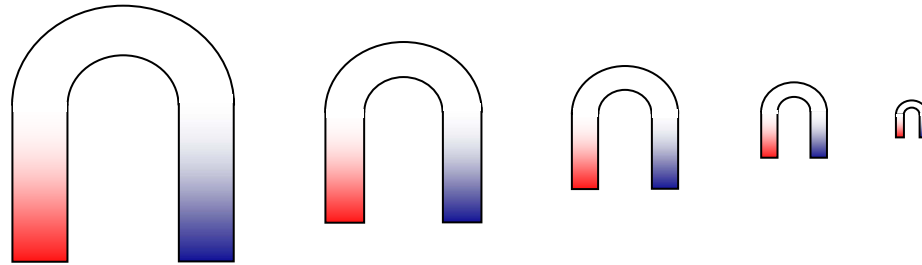


Giant magnetic anisotropy, size dependence



$\text{Co}_n/\text{Pt}(111)$
 $T = 5 \text{ K}$



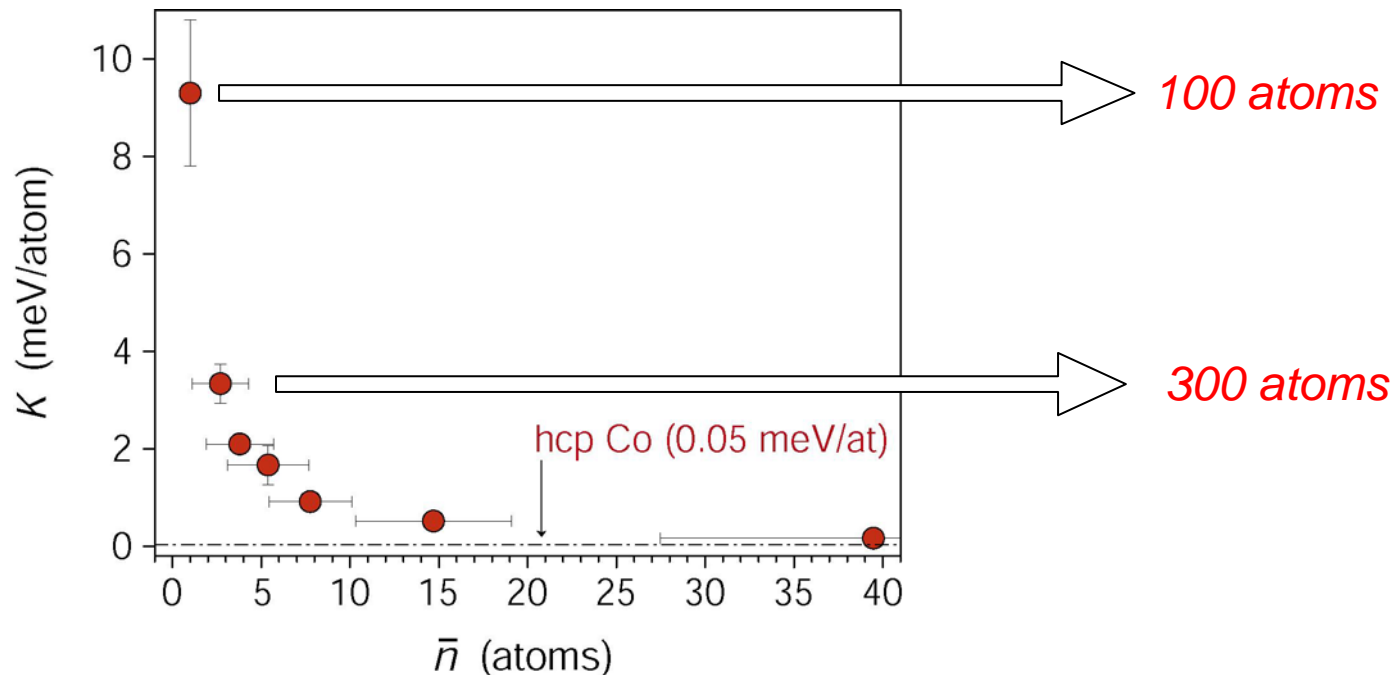


relaxation time of a magnetic particle: $\tau = \tau_0 e^{nK/k_B T}$

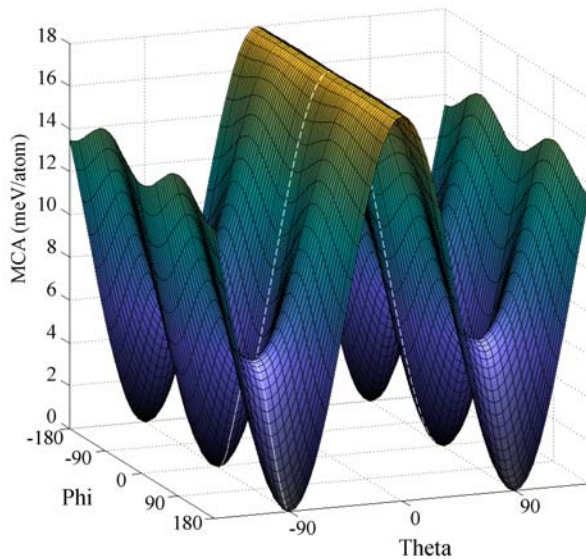
stability criterion: $\tau > 10$ years

$\Rightarrow nK/k_B T = 35$ @ $T = 350$ K

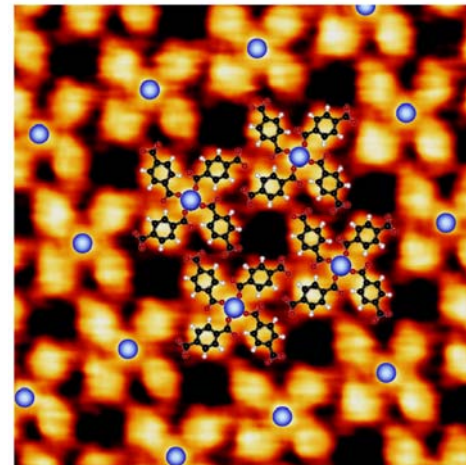
$\Rightarrow nK > 1$ eV



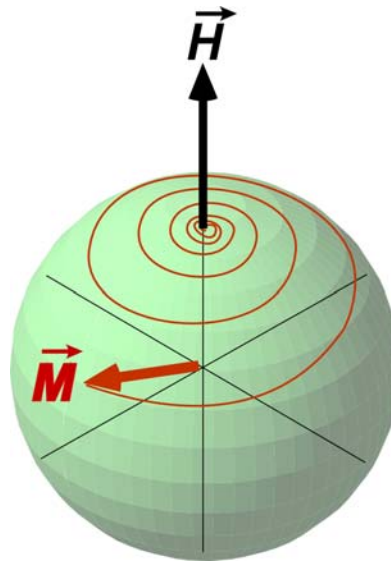
- Onset of magnetic anisotropy in single atoms on surfaces
- Coordination effects on orbital moment and magnetic anisotropy
- Miller-index dependence of single-ion magnetic anisotropy



*magnetic anisotropy
energy barriers*



*Supramolecular
metal-organic
networks*

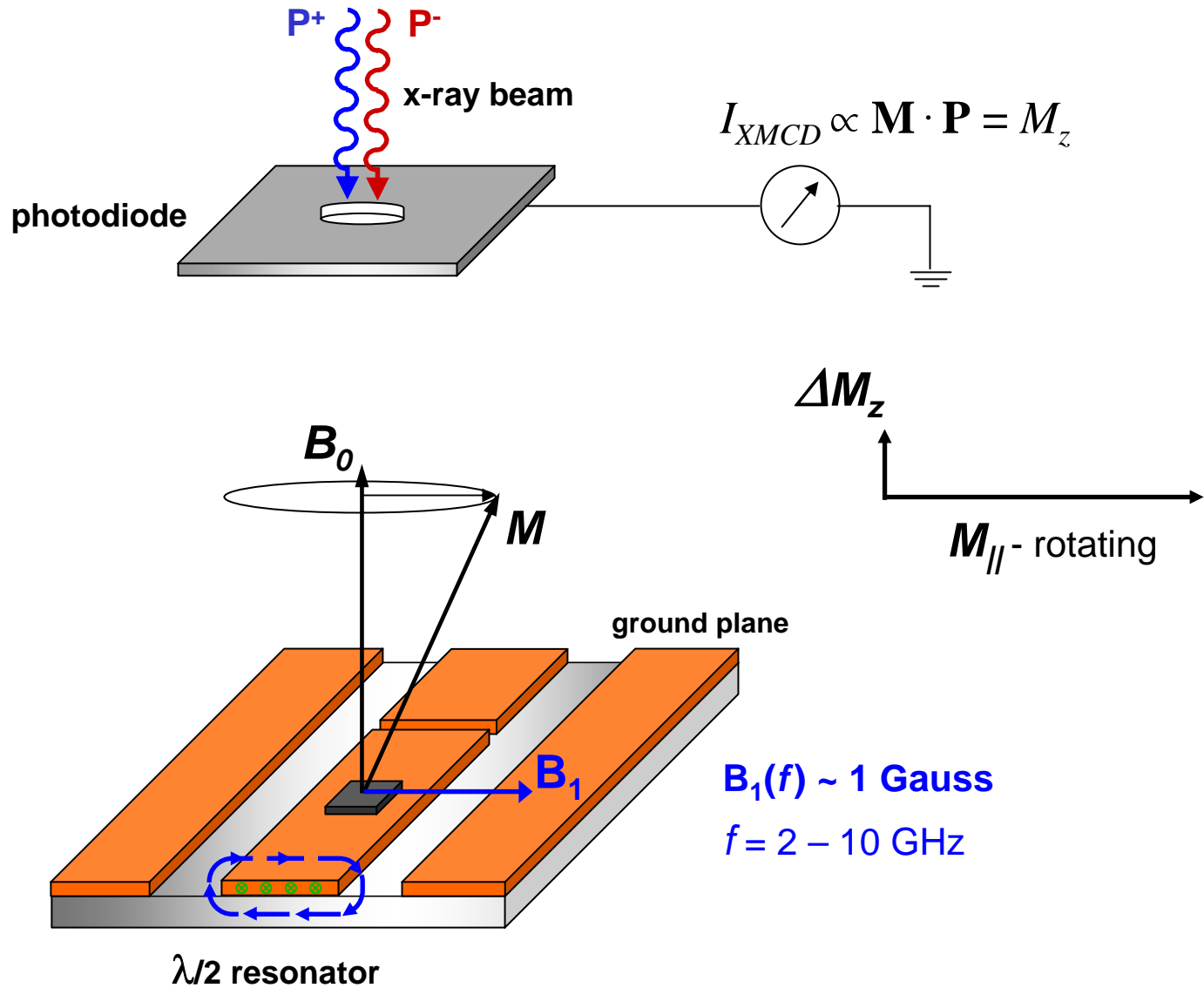


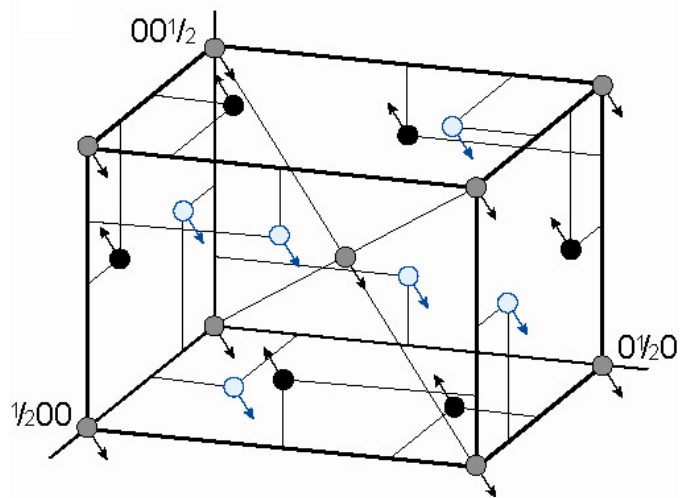
$$J = \underbrace{S_e + L_e}_{\text{magnetism}} + \underbrace{L_{\text{phonons}}}_{\text{lattice}} + \underbrace{L_{EM}}_{\text{excitation}}$$

XMCD : time- or frequency-resolved S_e, L_e

XAS : time- or frequency-resolved electronic structure

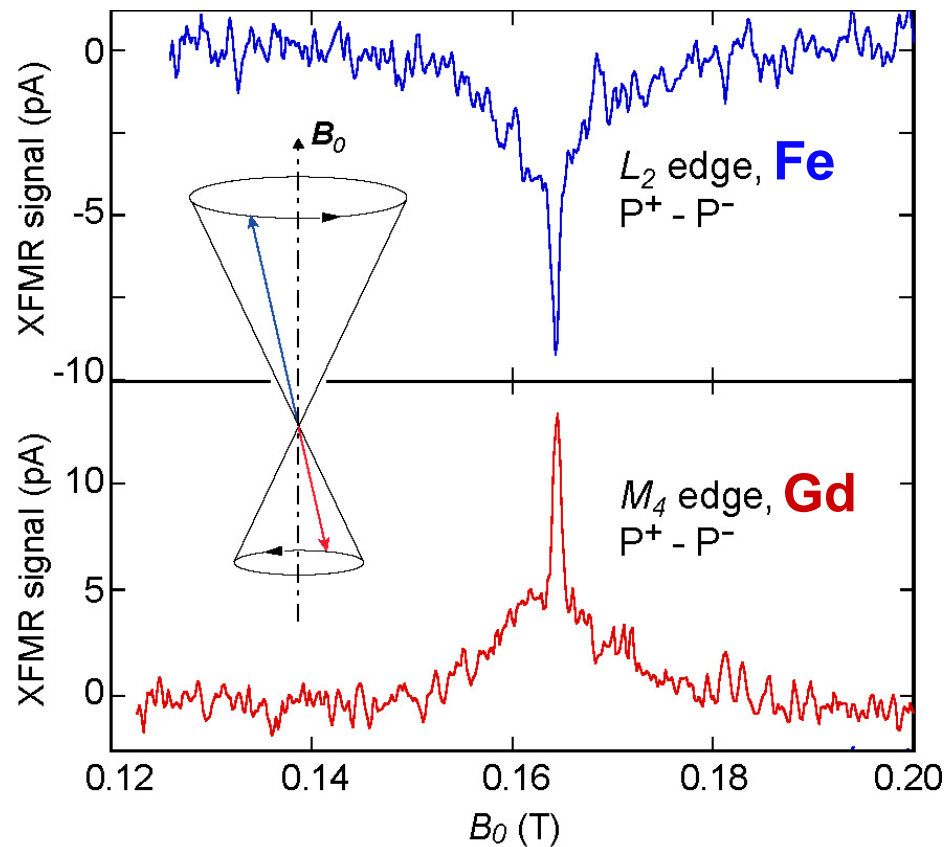
X-ray detection of ferromagnetic resonance – XFMR



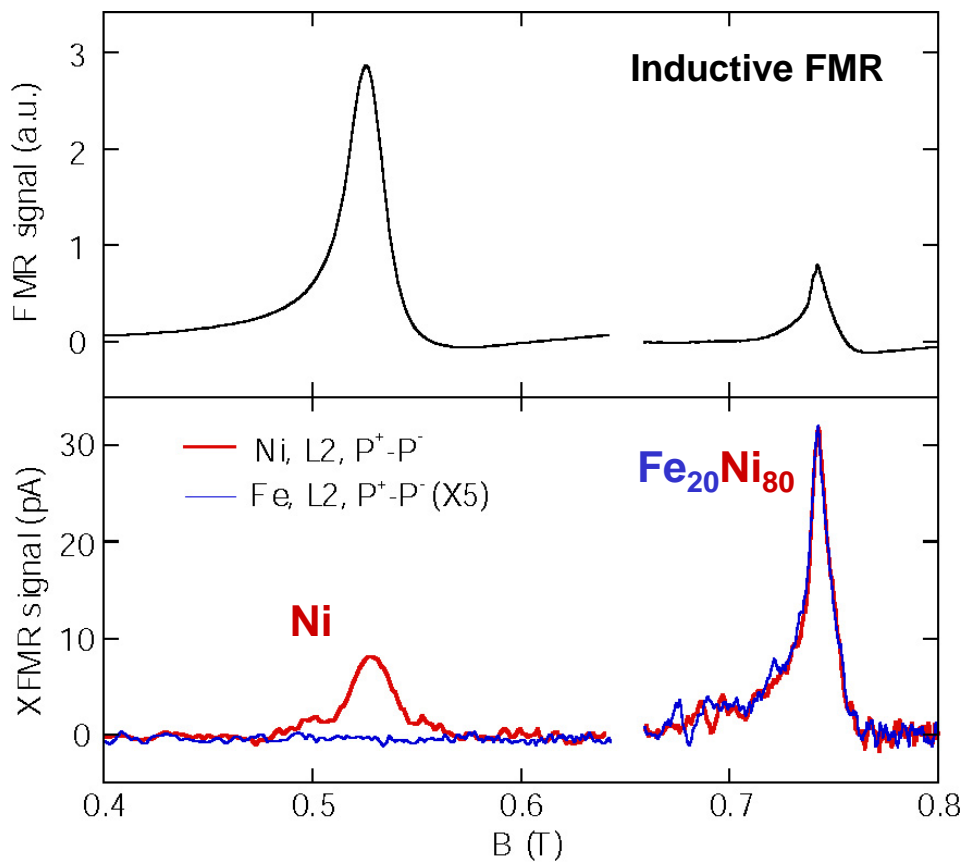
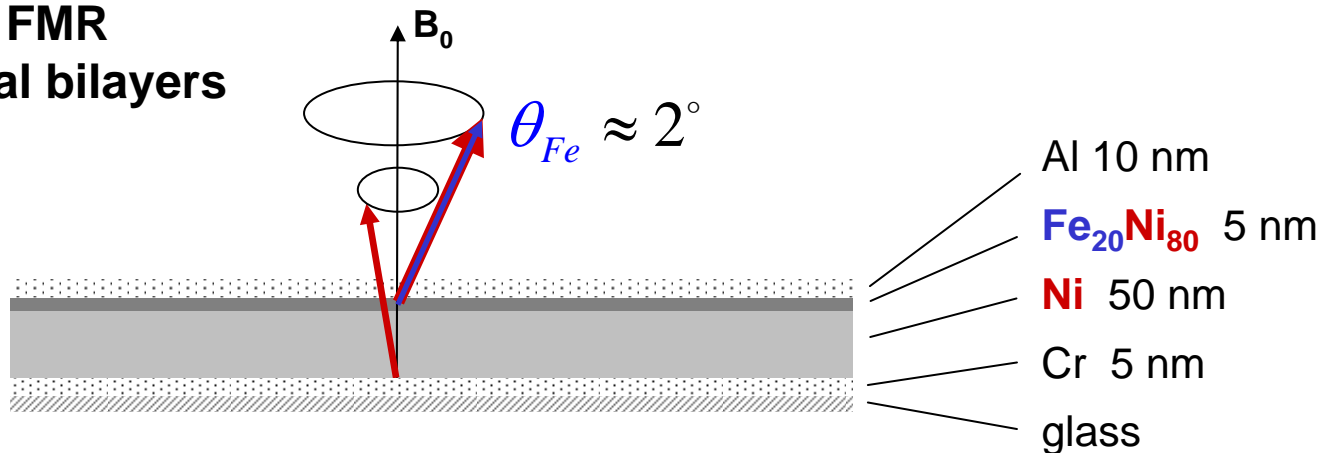


$f = 2.2 \text{ GHz}$

$B_1(f) \sim 0.35 \text{ mT}$



Layer-resolved FMR of coupled metal bilayers



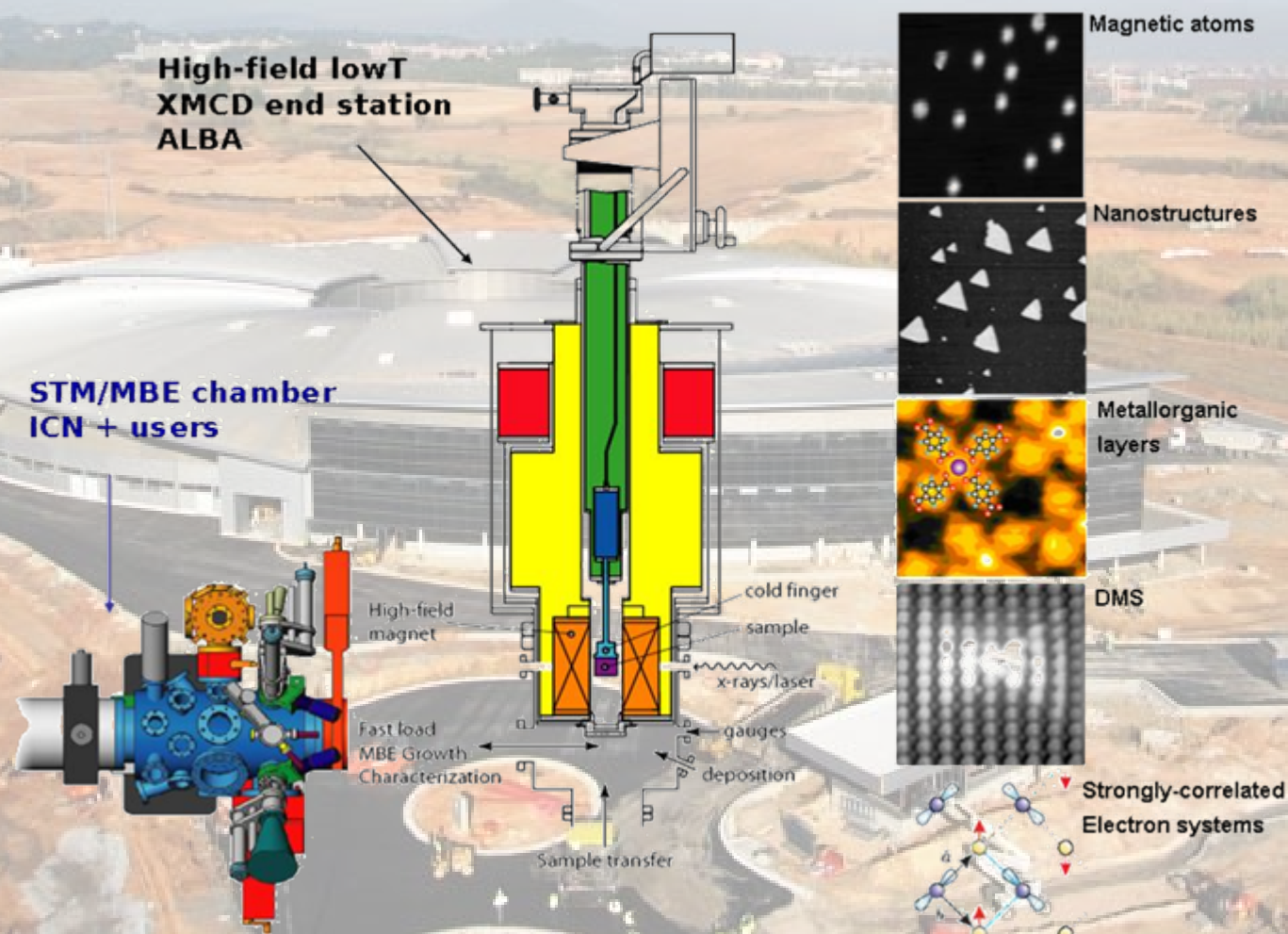
- No mutual resonance-driving effects
- Shifts of resonance positions

$$\Rightarrow E_{\text{exc}} \approx -0.6 \text{ erg/cm}^2$$

Boero et al.,
 New J. Phys. **10**, 013011 (2008).

The ICN – ALBA collaboration

Combine atomic-scale structural information with x-ray spectroscopy:



Contact person: G. Ceballos

XFMR

J. Kavich, A. Lodi-Rizzini, S. Stepanow – ICN – CIN2 Barcelona

G. Boero, S. Rusponi, EPF Lausanne

Magnetic impurities and nanoparticles:

S. Rusponi, H. Brune, EPF Lausanne

Synchrotron radiation measurements

S. Dhesi, P. Bencok, C. Tieg – ID08, ESRF

F. Nolting – SIM, SLS

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