Soft X-ray absorption Study of Magnetic Materials

09.09.2022 I Sabreen Hammouda
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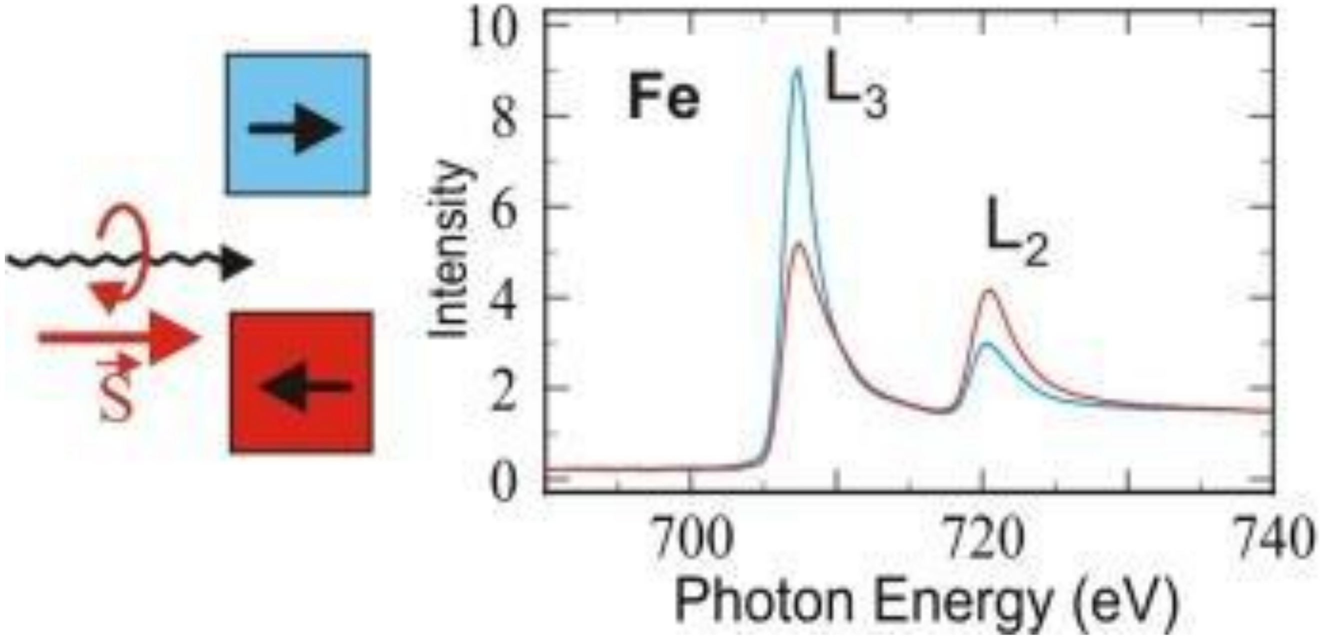
X-ray Magnetic Circular Dichroism (XMCD)

Dichroism: dependence of absorption on the photon polarisation



Element (& direction) sensitive (net) magnetization

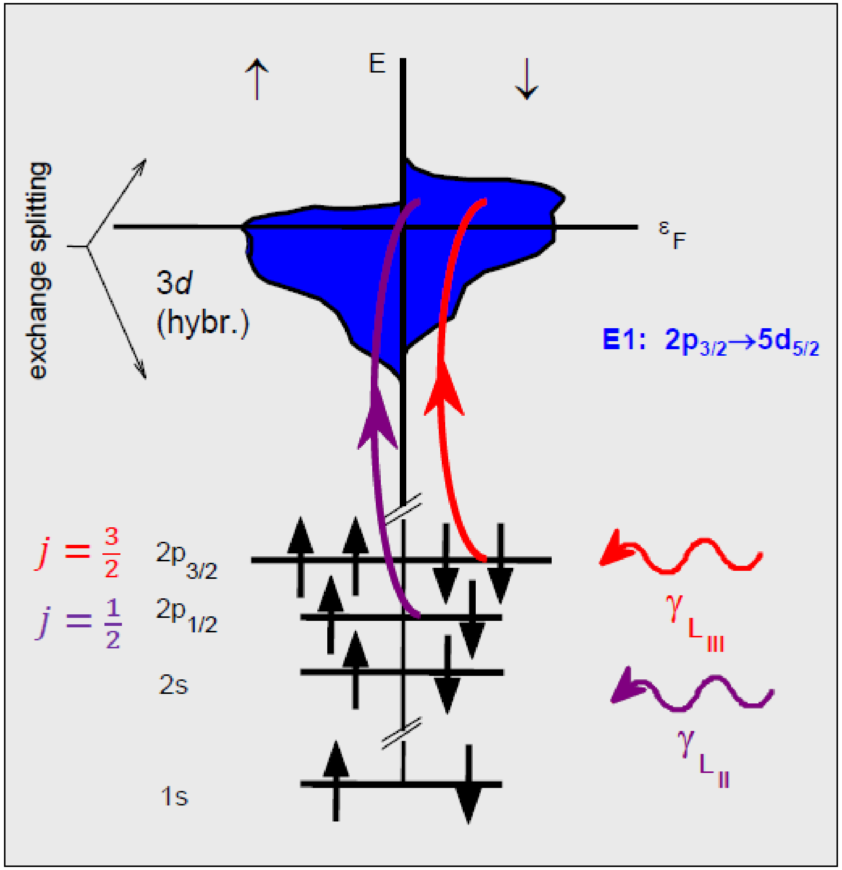
XMCD:

Absorption ∝ available final states

Two-step model:

Transfer of the photon helicity (angular momentum) onto the photo electron – due to spin-orbit coupling this goes partially onto the spin.

2. Transition with dipole selection rules ($\Delta\ell = \pm 1$, $\Delta s = 0$) probes free final states for the spin direction of the photo electron.



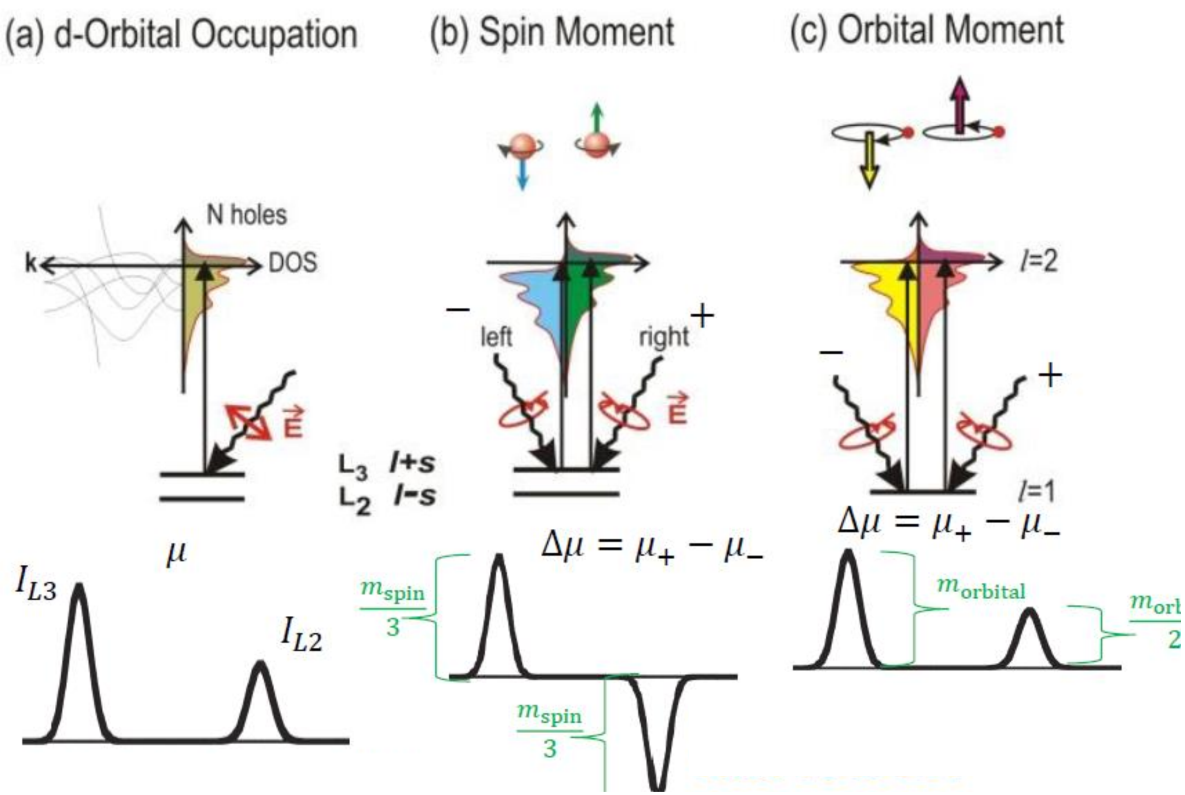
XMCD: sum rules

Also dependence on orbital moment (directly, helicity transferred to Δm_ℓ)

Opposite spin-orbit coupling in $p_{3/2}$ ($L3; j=\ell+s$) und $p_{1/2}$ ($L2; j=\ell-s$)

⇩

Spin- and orbital moments can be distinguished



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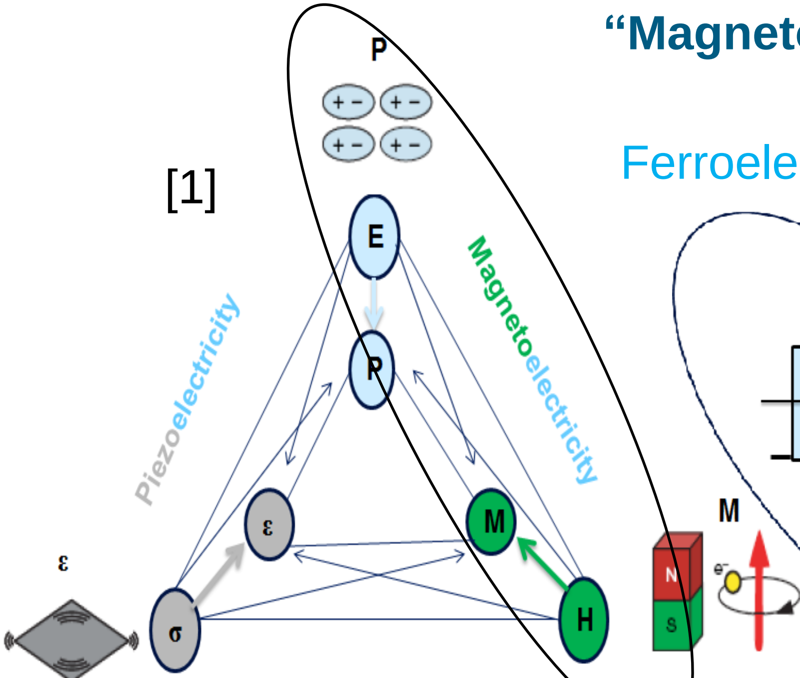
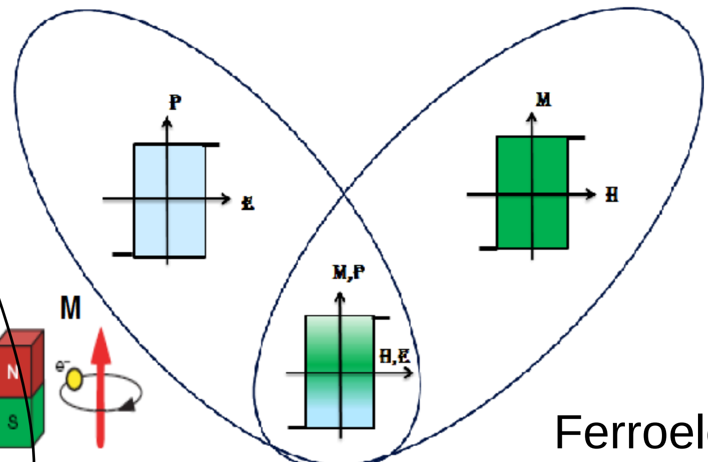
Multiferroics

“Magnetoelectric multiferroics”

[1]

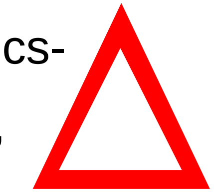


Ferroelectricity Magnetism



Magnetoelectricity

Multiferroics- ‘Contra-indication’



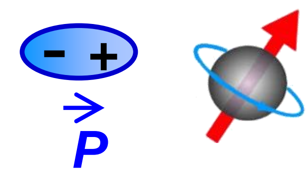
Ferromagnetism

Partially full *d* shell

Ferroelectricity

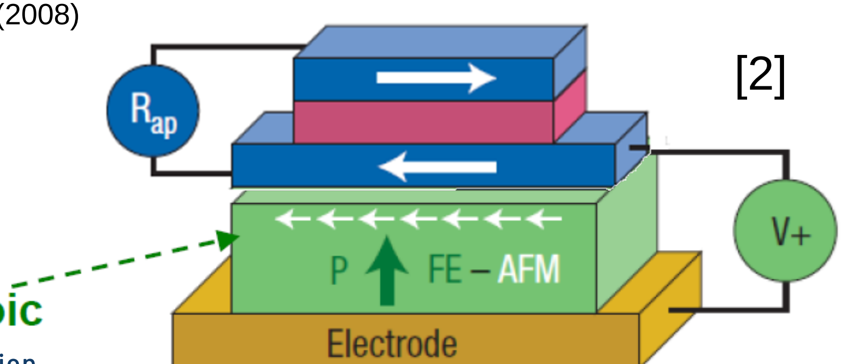
Empty *d* shell

Ferroelectricity: **Charge (Dipoles)**



[1] Velev et al., Phil. Trans. R. Soc. (2011)

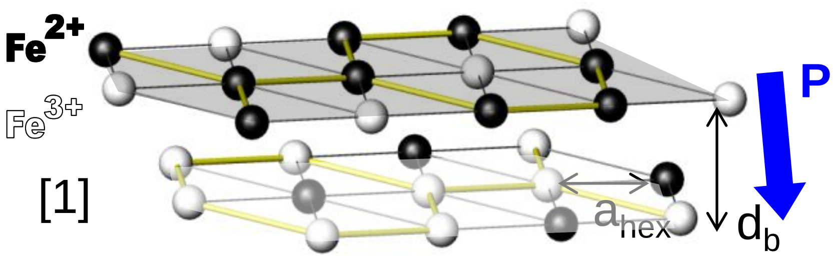
[2] Bibes and Barthelemy, Nat. Mater. (2008)



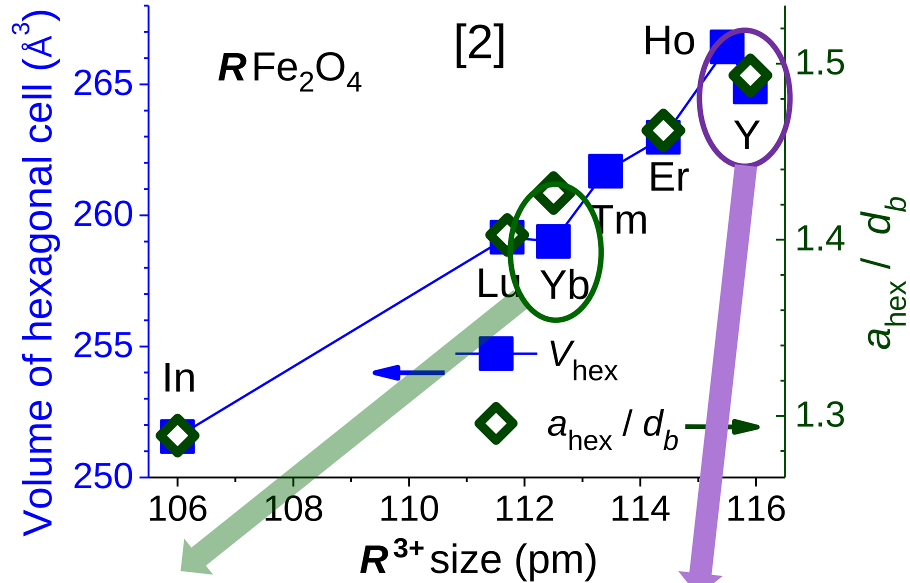
[2]

“Magnetic random-access memory”

Ferroelectricity through charge order?



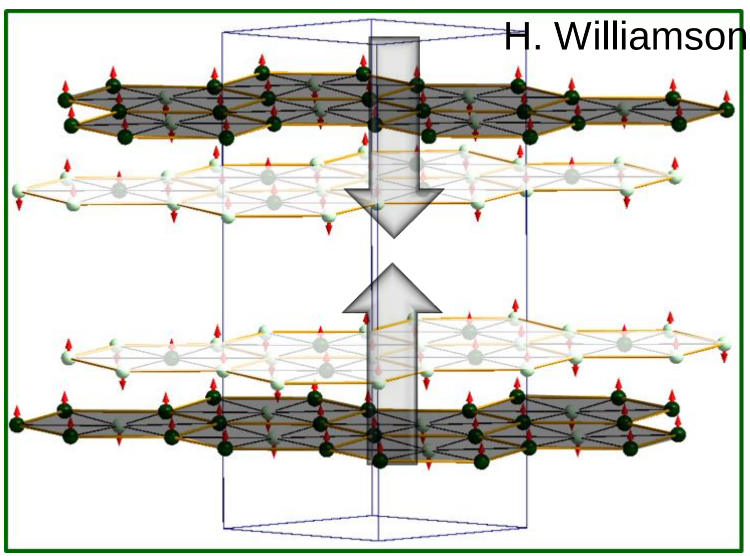
Bilayer subunit in RFe_2O_4 compounds.



[1] Ikeda et al., J. Phys: Condens. Matter (2008)
[2] Angst, Phys. Status Solidi RRL (2013)
[3] Angst presentation

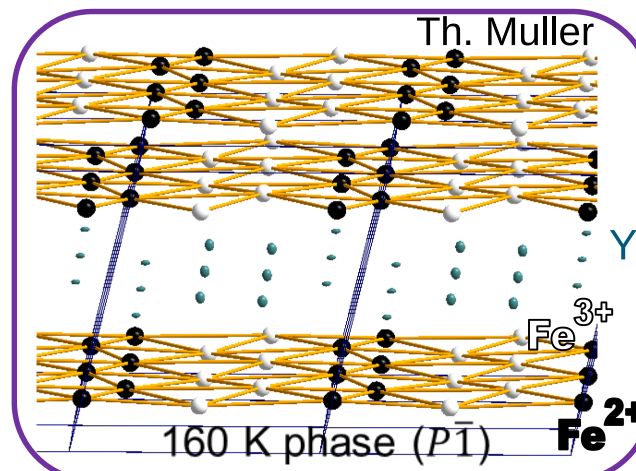
$LuFe_2O_4$ proposed to be a magnetoelectric multiferroic through valence ordering.

Fe_3O_4 is a proper example.



[3]

Commensurate $YbFe_2O_4$

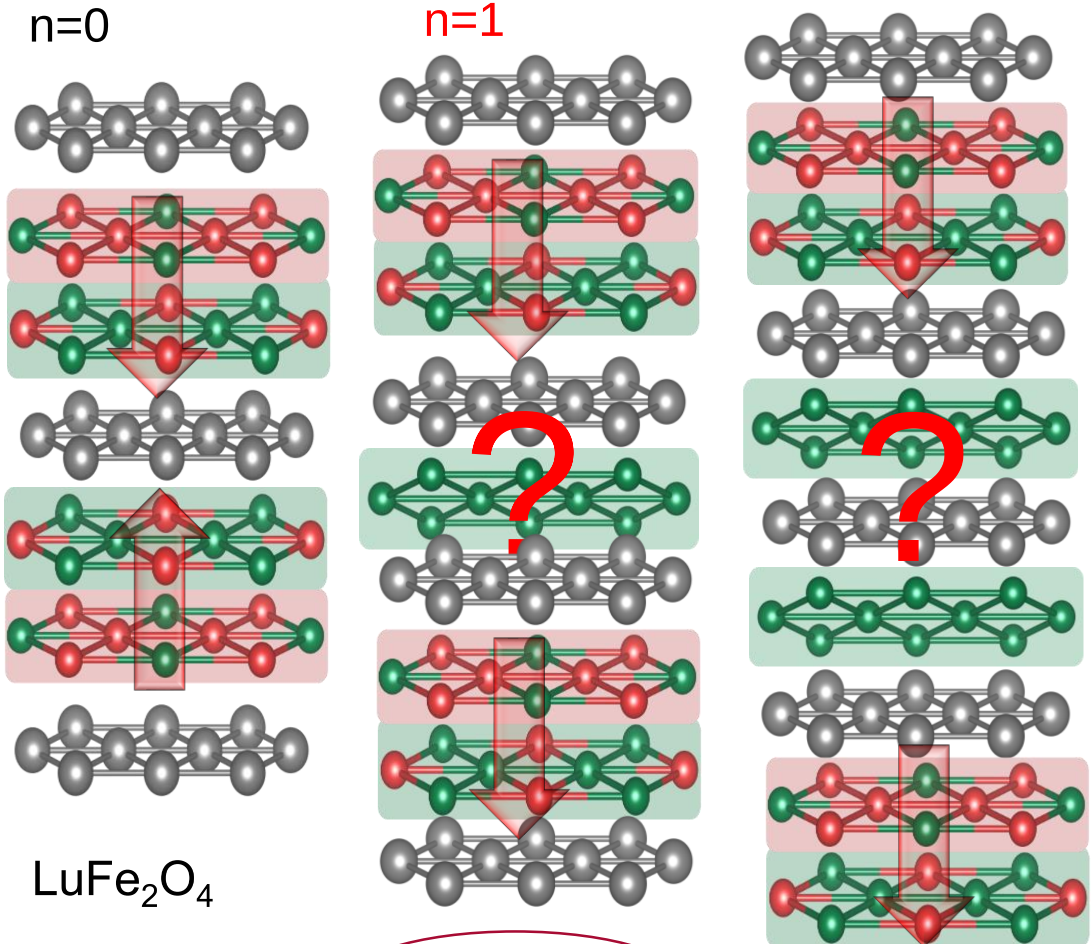


Structure of $LuFe_2O_4(LuFeO_3)_n$ (n=0,1,2)

n=0 n=1 n=2

$Fe^{3+}Fe^{2+}$/O

Lu/O



$LuFe_2O_4$

$Lu_2Fe_3O_7$

$Lu_3Fe_4O_{10}$

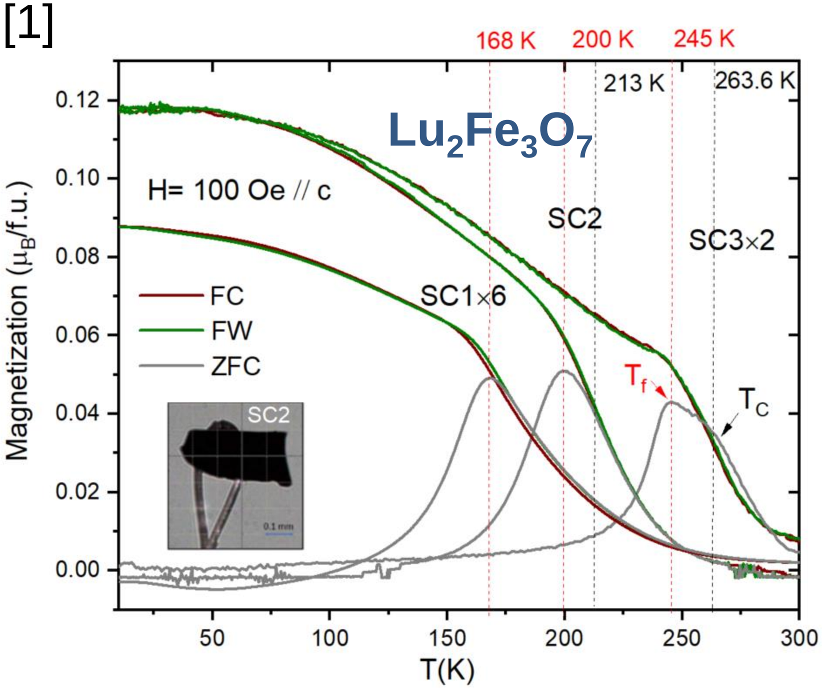
- Rhombohedral ($R\bar{3}m$, n even) [1]
- Hexagonal ($P6_3/mmc$, n odd) [2]

- Mössbauer spectroscopy studies : Fe-O mono-layer Fe^{3+} ions, while the bilayer contains $Fe^{2.5+}$ [3,4]

[1] Matsui, J.Appl. Cryst. (1980)
[2] Kimizuka et al., Acta Crysta. (1976)
[2] Matsui et al., Acta Crysta. (1979)
[3] Tanaka et al., J. Magn. Magn. Mater. (1983)
[4] Tanaka and Iida, Hyperne Interact. (1994)

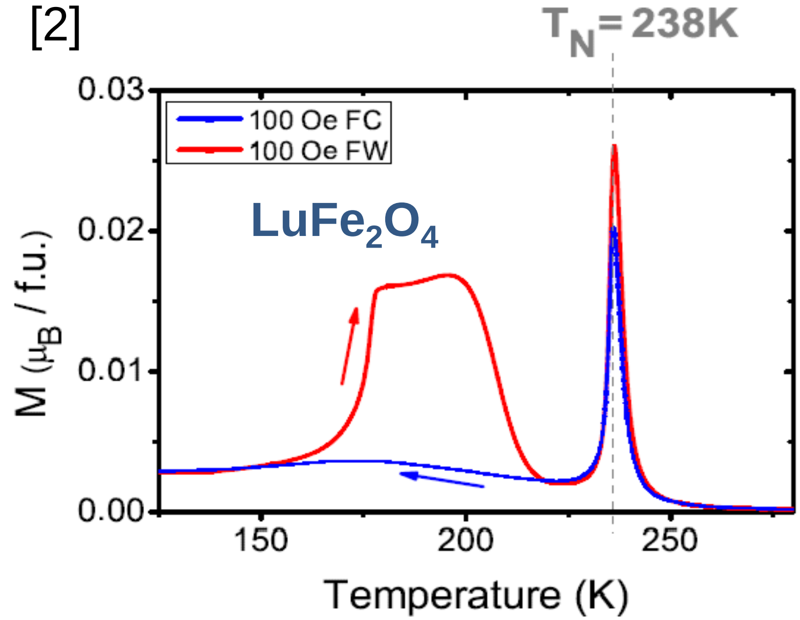
Magnetic properties vs stoichiometry

[1]



0.4*0.20*0.05 mm^3

[2]



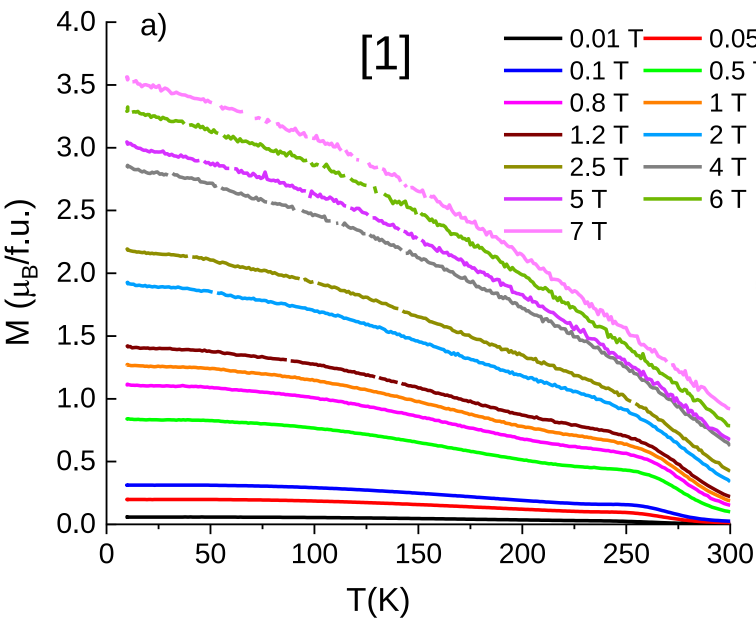
Crystal : CO_2:CO
SC1:50
SC2:85
SC3:85
S1:90
S2:85

- Best *M(T)* curves still have no sharp features as observed for not intercalated compounds
- Variations even within one batch.
- Crystals with higher oxygen content are smaller

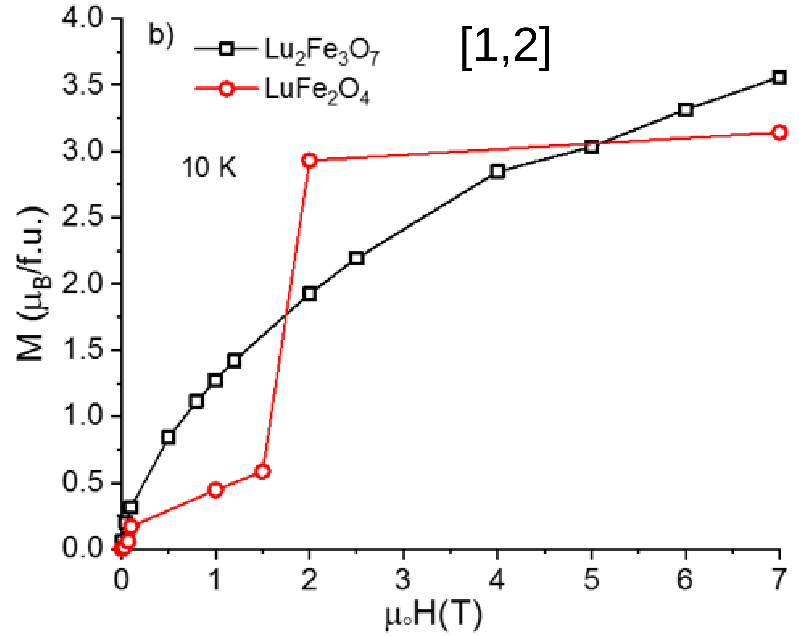
[1] Hammouda et al., Phys. Rev. B 104, 174437

[2] de Groot, Ph.D. thesis, RWTH Aachen university. (2012)

The high field studies on $Lu_2Fe_3O_7$ (SC3)

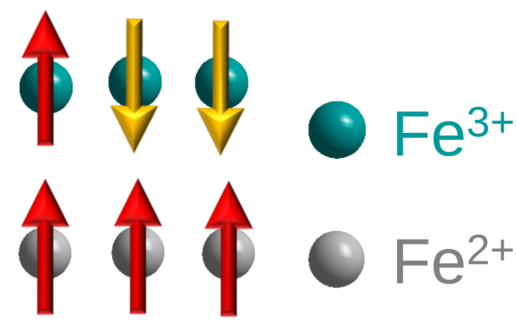


Field-cooled/warmed magnetization



Low -T field cooled magnetization

- Moment of ~3 $\mu_B/\mathrm{f.u.}$ arises from specific spin arrangement and indicates similar spin arragnemnet as in the bilayer of $LuFe_2O_4$
- An additional H-induced contribution is from the single layer spins.



[1] Hammouda et al., submitted to PRB.

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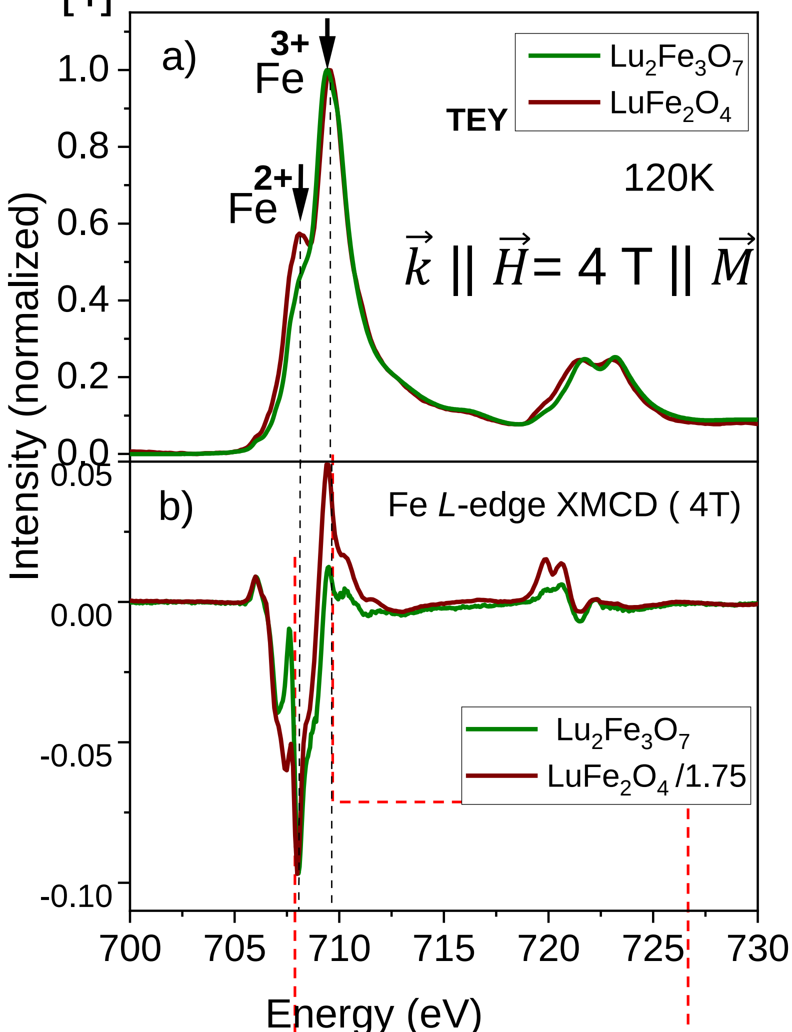
[2] $LuFe_2O_4$ data from de Groot, Ph.D. thesis, RWTH Aachen university. (2012)

X-ray magnetic circular dichroism (XMCD) on SC3

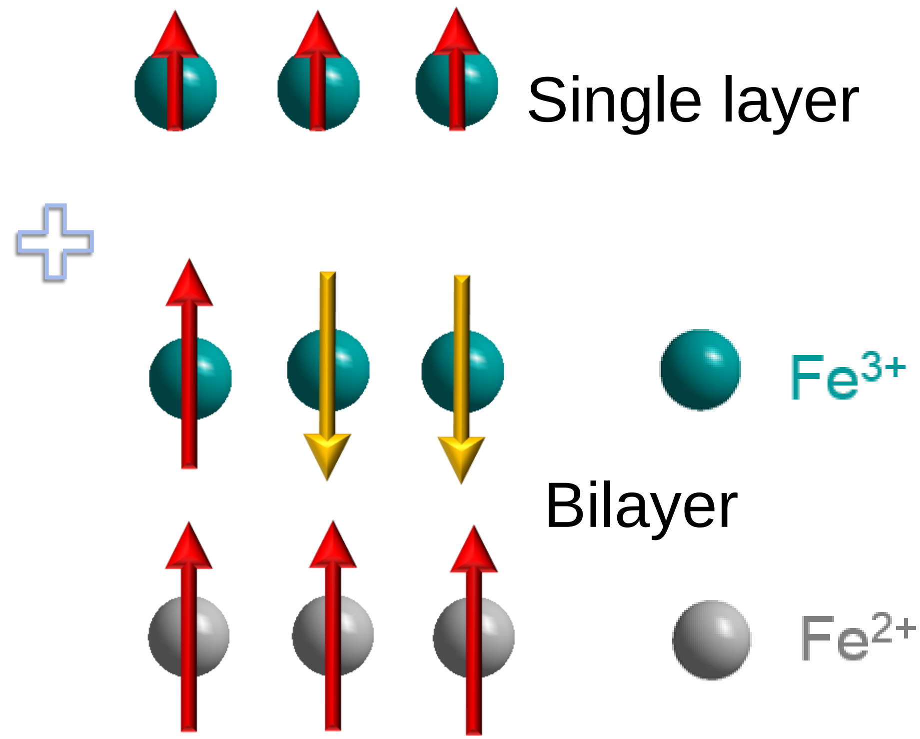
[1]



XMCD data probing Fe edge $L_{2/3}$

$$\Delta\mu = \mu_+ - \mu_-$$

to deduce the net spins belonging to the different valances



1/3 of Fe^{3+} point same direction as Fe^{2+}

Fe^{2+} net spin along *H*

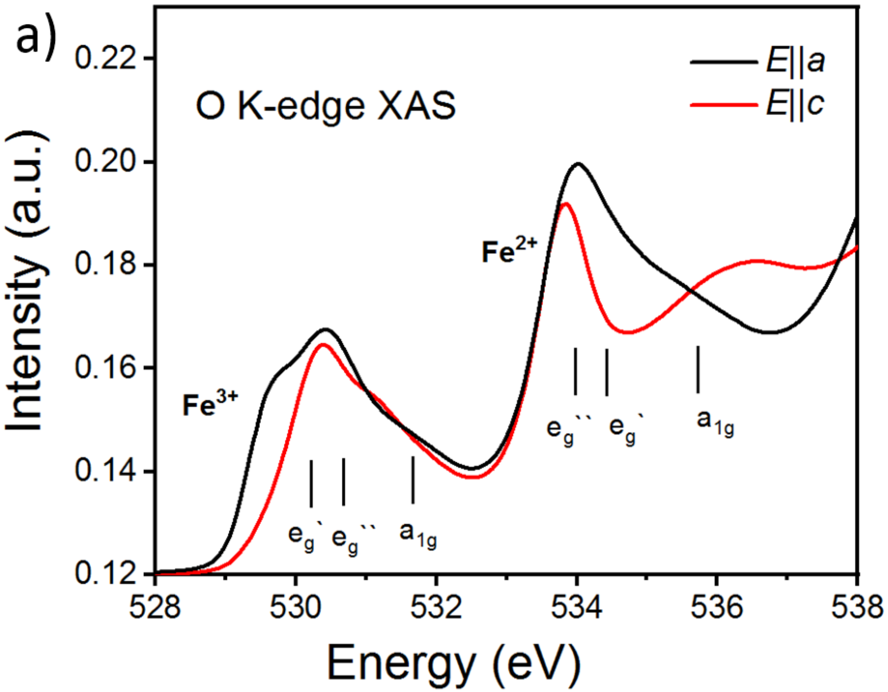
Smaller Fe^{3+} net spin opposite to *H*

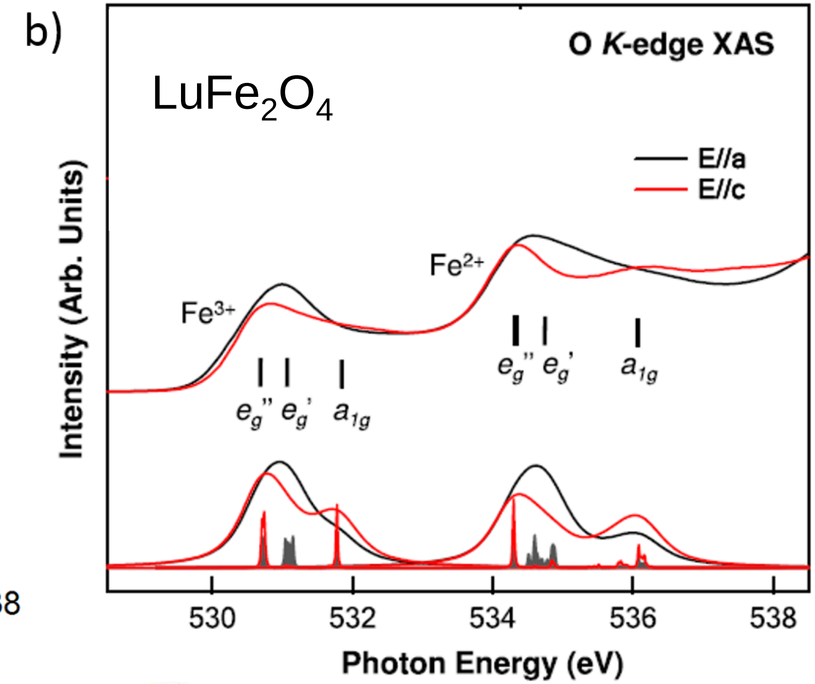
[1] Hammouda et al., Phys. Rev. B 104, 174437

$LuFe_2O_4$ data are from [de Groot, Ph.D. thesis, RWTH Aachen university. (2012)]

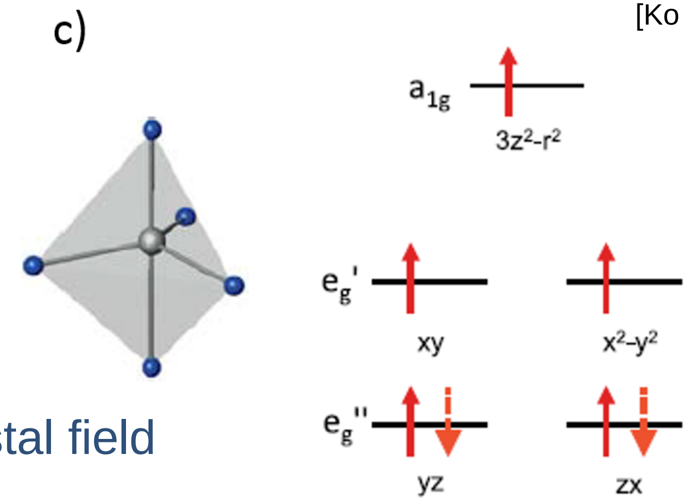
Linear X-ray absorption spectra (LXAS) on SC3

[1]





[Ko et al., Phys.Rev.Lett. (2009)]



$\vec{E}$ || c is sensitive for the orbital state in a_{1g}

$\vec{E}$ || ab is sensitive for the orbital state in eg’

The super exchange interactions are very similar in the bilayer

Trigonal-bipyramidal crystal field

[1] Hammouda et al., Phys. Rev. B 104, 174437

[Angst, Phys. Status Solidi RRL (2013)]

Summary

1. Single crystals $Lu_2Fe_3O_7$ exhibit no long-range spin order.

2. Similar spin order in the bilayer as in $LuFe_2O_4$:

- comparable net moment to the bilayer of $LuFe_2O_4$
- $\frac{1}{3}\frac{1}{3}$ in-plane propagation.
- similar shape of the XMCD with net moment of the Fe^{2+} is the same

3. In the single layer, spins are paramagnetic-like in the first approximation.

4. Spin-charge coupling by XMCD, similar CO

Outlook

- Similar experiments will be done on quantum materials at HESEB.

Acknowledgements

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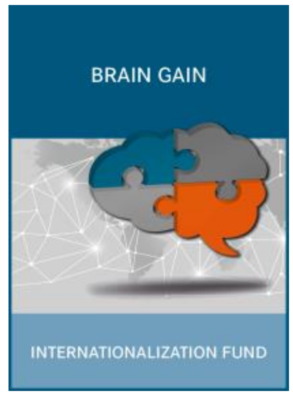

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Thanks for your attention!