POLITECNICO DI MILANO

ID 20 magnetic scattering

ESRF

Resonant Elastic X-ray Scattering and Neutron Scattering investigation of Magneto-Electric materials

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Synchrotron group, Physics Dep., Politecnico di Milano

Outline

- Multiferroics and MagnetoElectrics
- REXS technique point of view on electronic degrees of freedom
- REXS and neutron investigations of MEs: some relevant cases in external fields
- Conclusions

Collaborators

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- J. Geck (IFW, Dresden, D)

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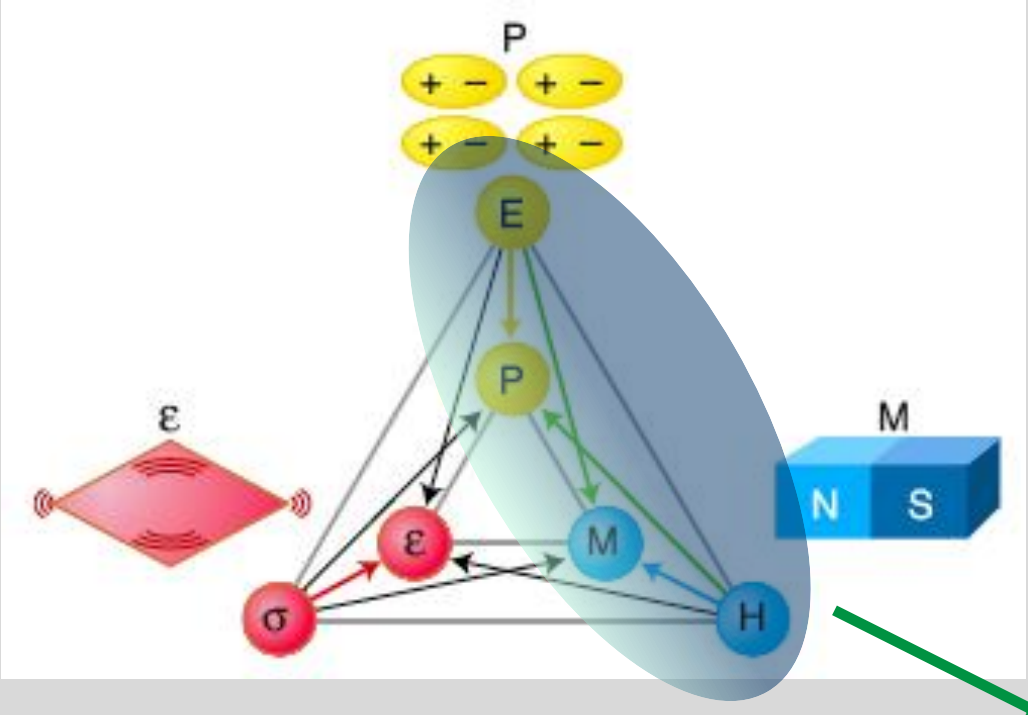
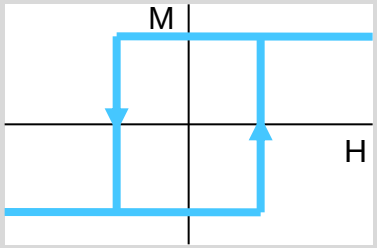
- V. Scagnoli (SLS, PSI, Villigen, CH)

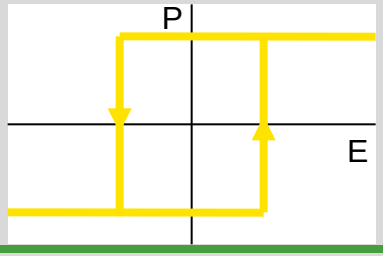
- H. C. Walker (P09, Petra, DESY, Hamburg, D)

EO in multiferroics and magnetoelectrics

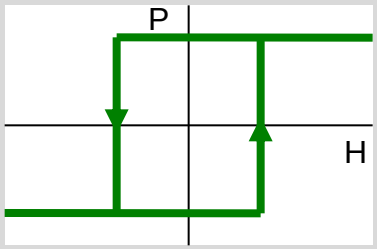




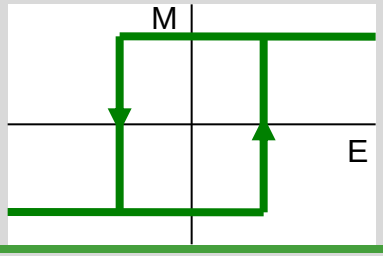
Magnetization vs magnetic field in FMs



Polarization vs electric field in FEs



Polarization vs magnetic field in MEs



Magnetization vs electric field in MEs

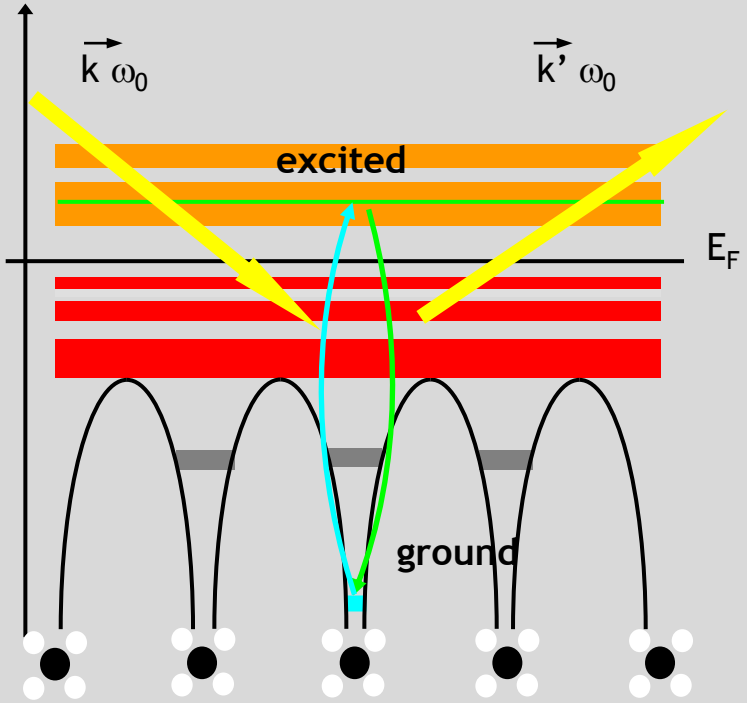
- **Ferroic**: P, M or ε have divergent components at Q=0, so giving rise to ferroelectricity, ferromagnetism or ferroelasticity
- **Multiferroic**: coexistence of at least two kinds of long-range ordering
- **Magnetoelectrics**: cross control P (M) via H (E)

REXS principles: absorption + scattering

• Electromagnetic field (photons) as a probe for e^- states of the matter (**A** $_{\text{radiation}} \leftrightarrow$ **E, B** $_{\text{atomic charges}}$)

• Chemical selectivity
(absorption related → site and band selective)

• 3D e^- distributions
(due to atomic scattering factor, in diffraction condition, site contrast due to structure factor)



array of resonating ions

• to fulfill Bragg's law:
$\lambda \sim$ atomic spacing $\leftrightarrow$ keV (hard regime: K 3d, L 4f, M 5f; soft regime: $L_{2,3}$ 3d)

REXS → RXD

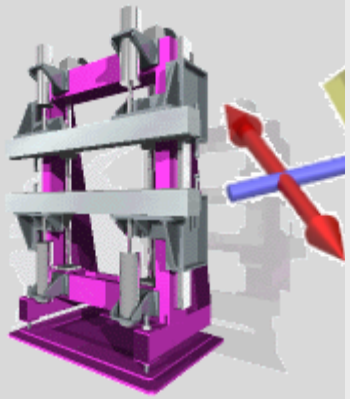
CM et al., EPJ-ST 208 (2012) 89

REXS experiments: measurement strategies

$$I_{RXS} \propto \left| f(\omega_0, \quad ') \right|^2$$

CM et al.
PRB 76 (2007) 195118
V. Scagnoli, CM et al.
JSR 16 (2009) 778

1' Change the polarisation of the incide

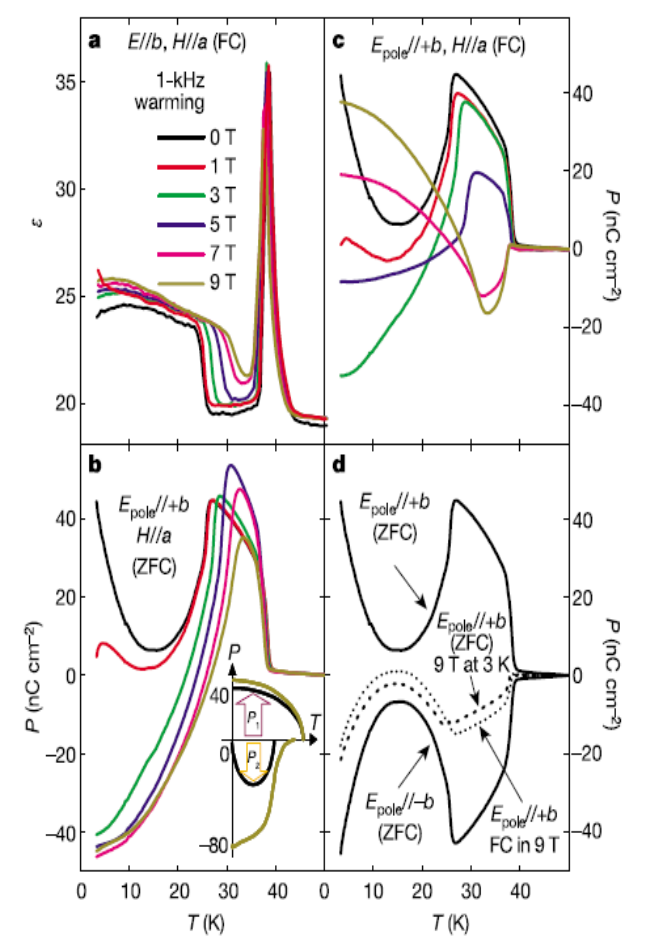


1 Azimuth variation θ_{PA} axis

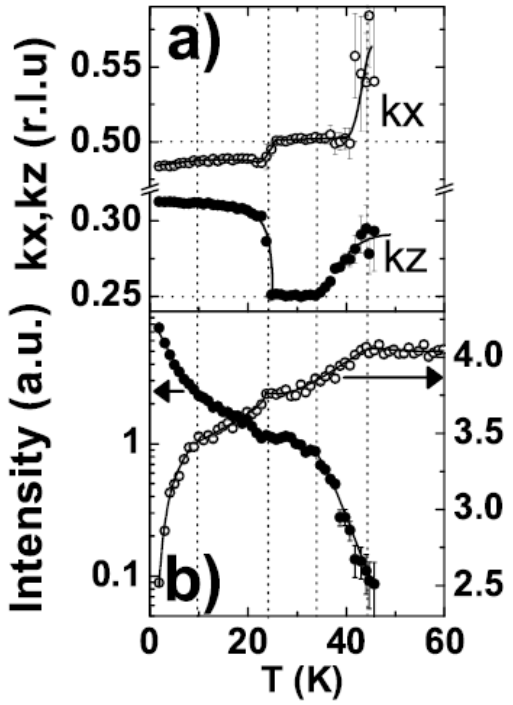
2 Measure the intensity of the diffracted beam vs. the linear polarization dir.

Azi-scan (ψ) or pol-scan (η): "complementary" information

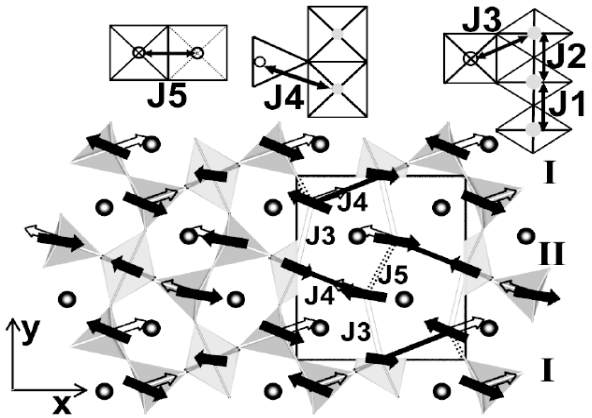
$TbMn_2O_5$: ME is spin mediated



N. Hur et al.
Nature 429 (2004) 392



L.C. Chapon et al.
PRL 93 (2004) 177402
G.R. Blake et al.
PRB 71 (2005) 214402

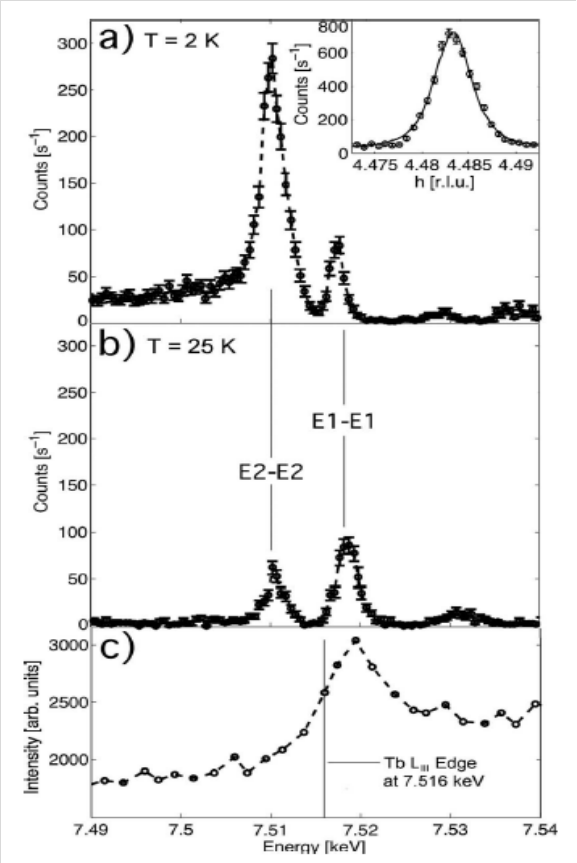


CM structure

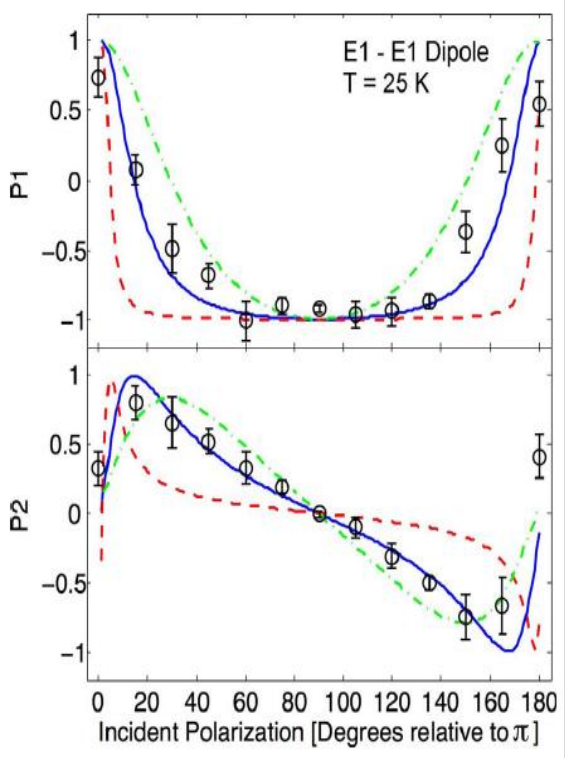
In $TbMn_2O_5$
Mn collinear magnetic structure
breaks the inversion symmetry!

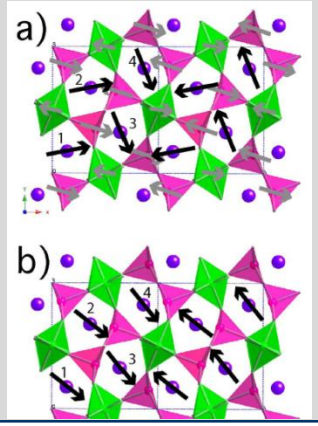
Tb spins in $TbMn_2O_5$

At Tb L3-edge



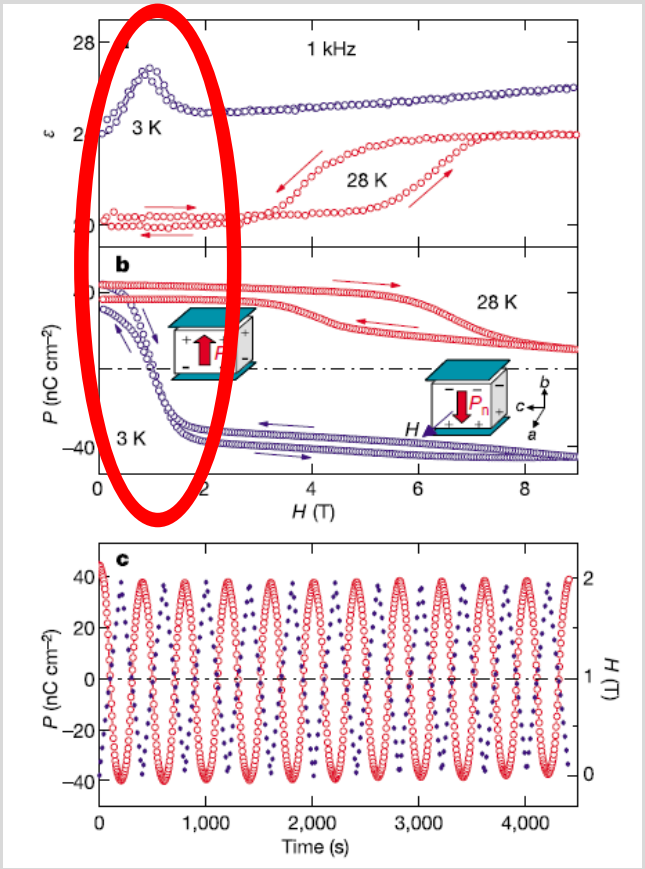
R.D. Johnson, CM et al.
PRB 78 (2008) 104407





CM

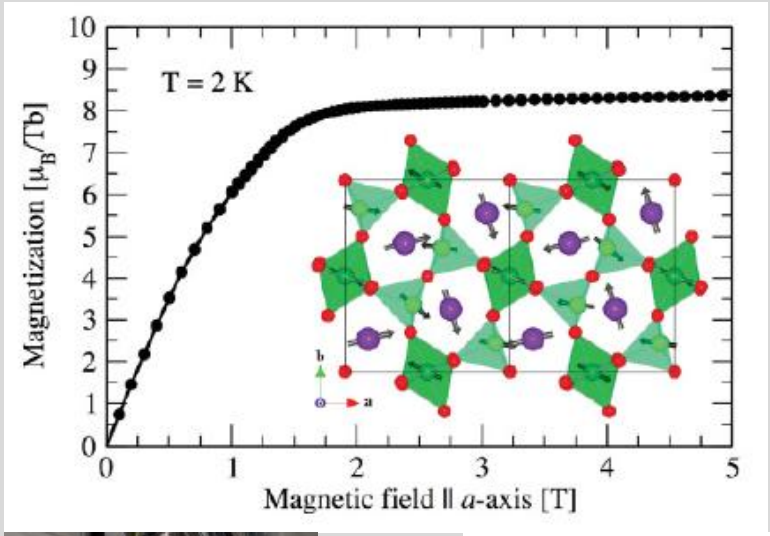
ICM



P reversed by H in ICM

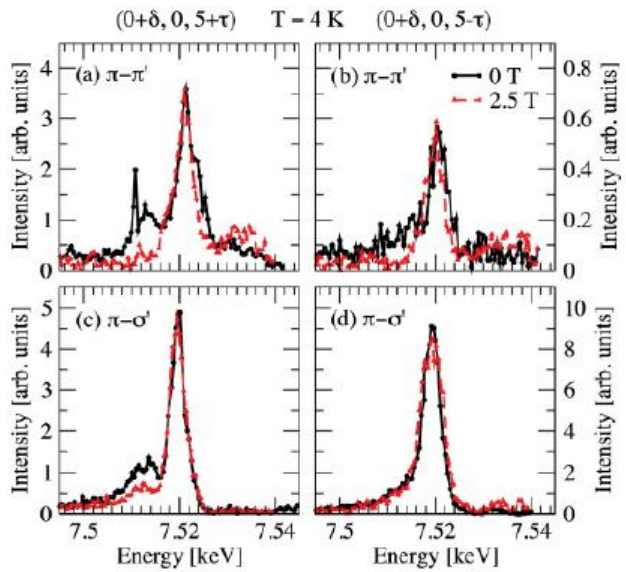
Tb spins are not collinear to Mn ones

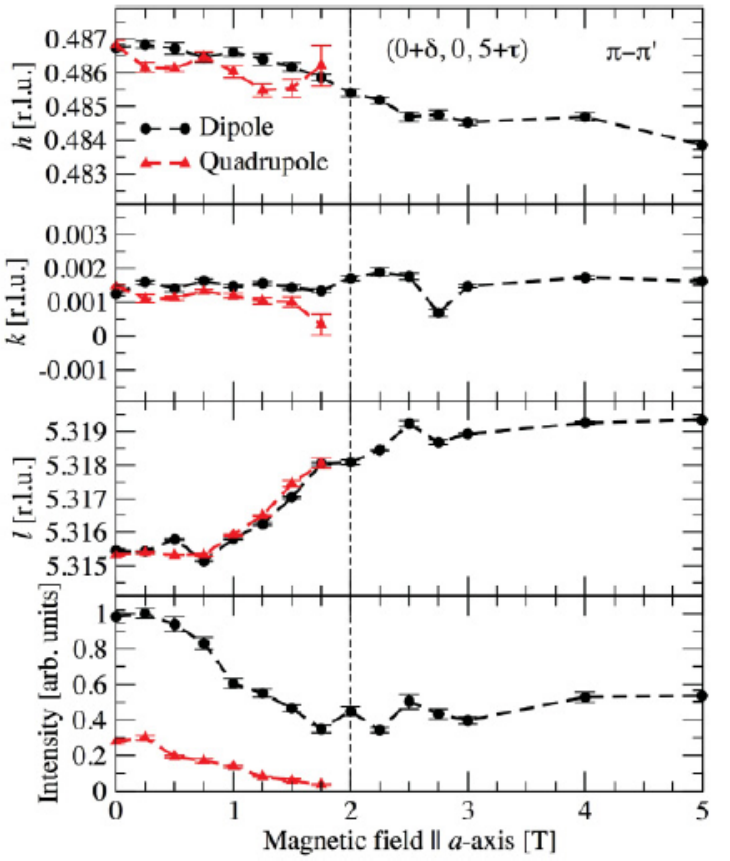
Tb spins role in $TbMn_2O_5$



Tb spins are actors of the P reversal, not just spectators

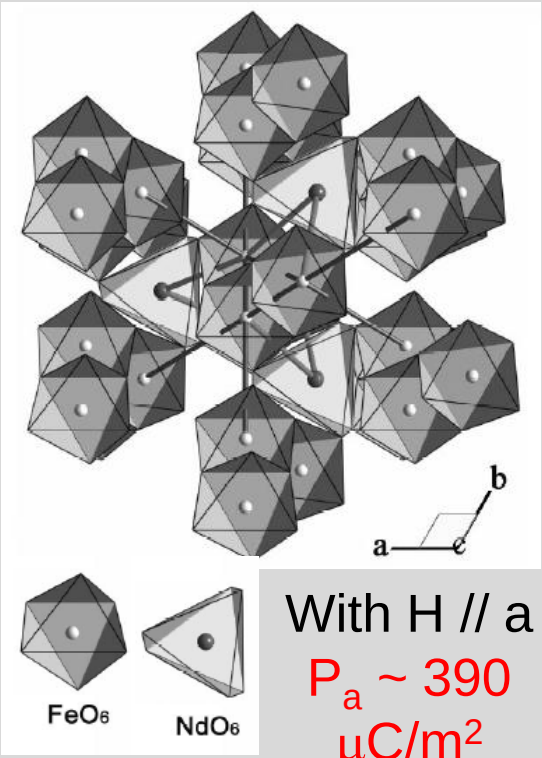
R.D. Johnson, CM et al.
PRB 83 (2011) 054438



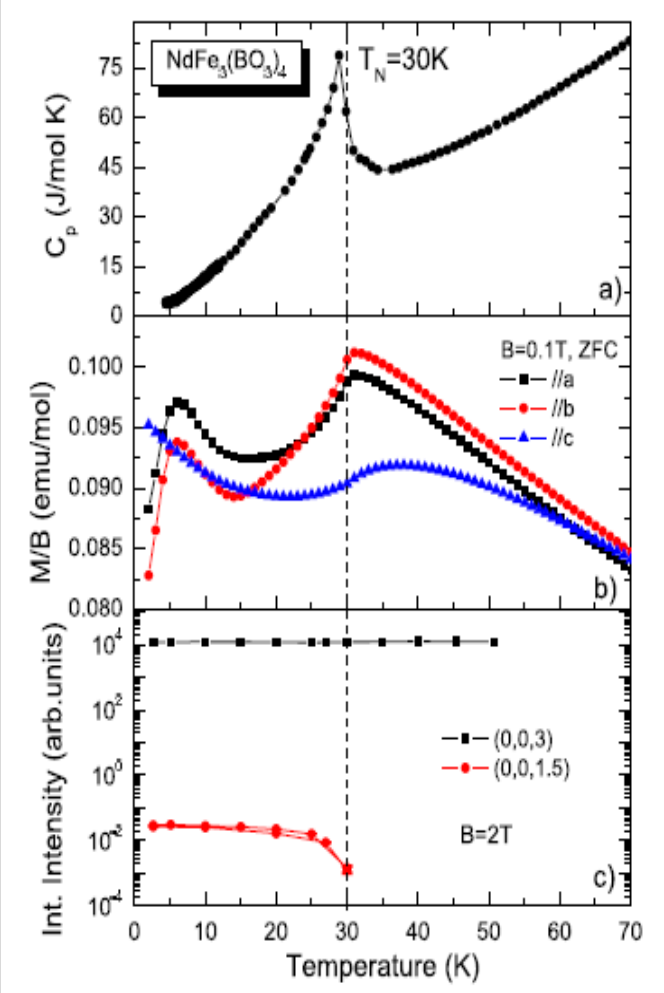


$NdFe_3(BO_3)_4$: which mechanism?

At RT: R32, although
no inversion symmetry
SG is non-polar so
no net P allowed
by the structure!

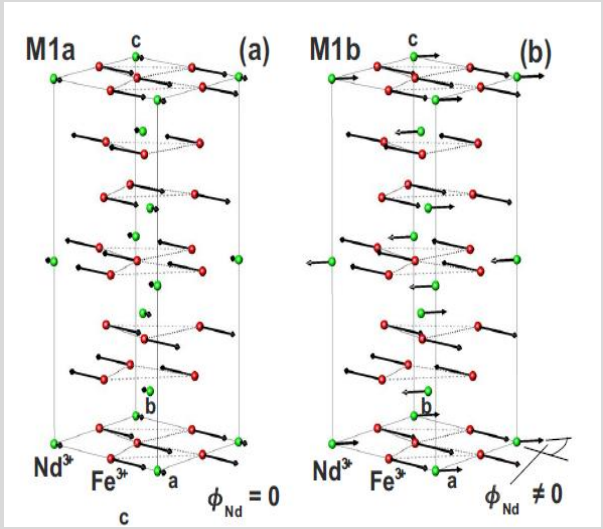


With H // a
P_a ~ 390
$\mu C/m^2$



J.E. Hamann-Borrero et al.
PRB 82 (2007) 094411

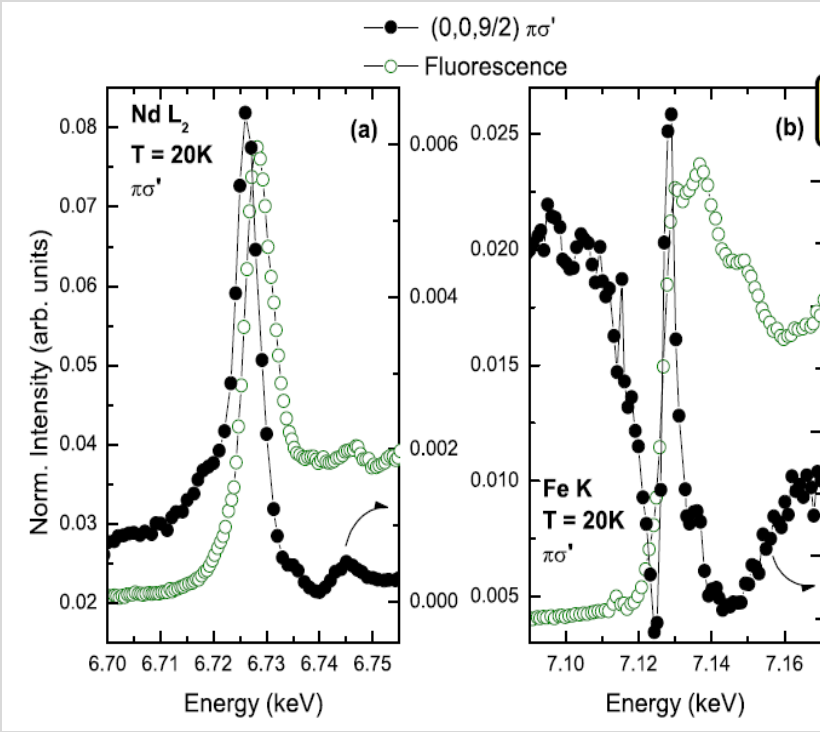
M. Janoschek et al.,
PRB 81 (2010) 094429

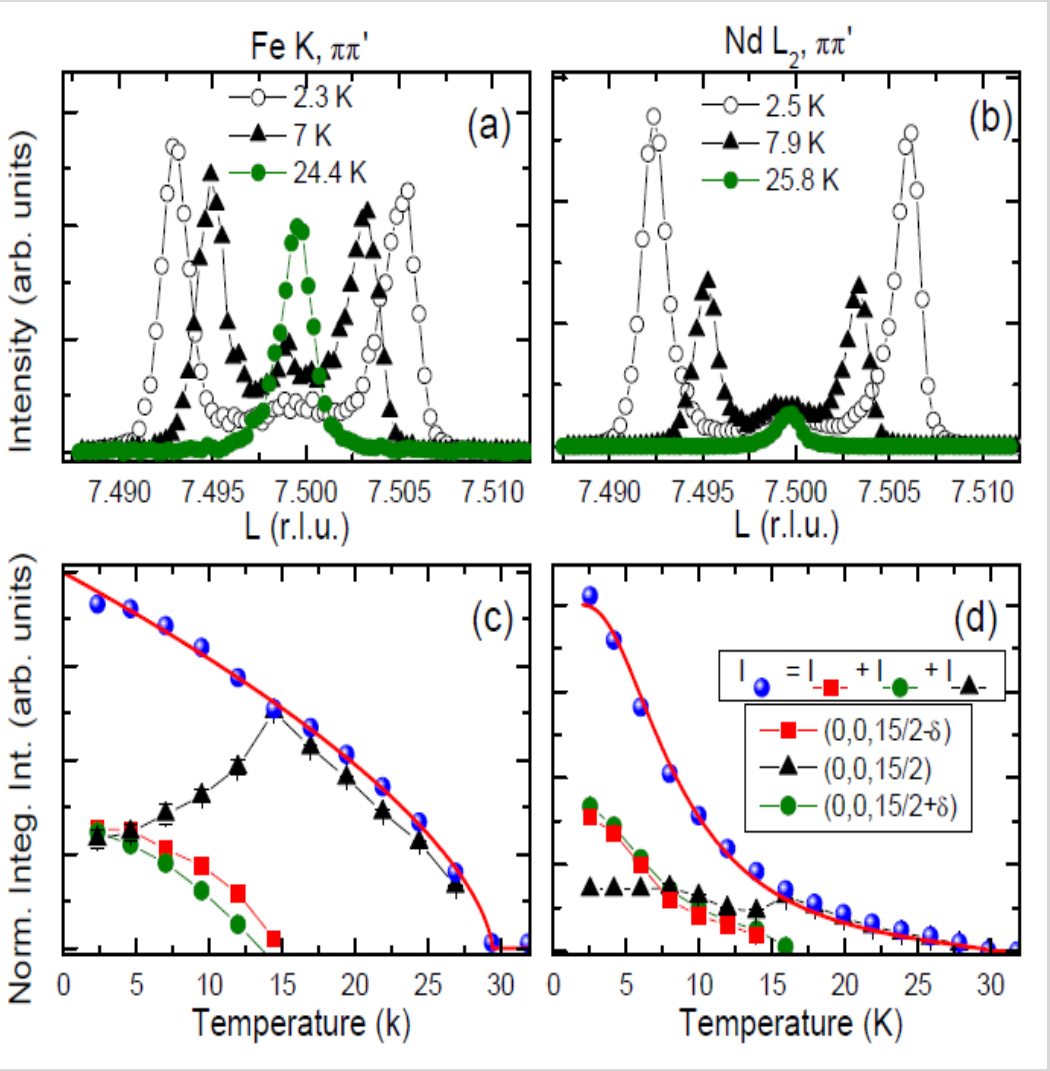


$q = [0\ 0\ 3/2+\delta]$
e_{ij} // c*
P = **e** x **q** = 0!

$NdFe_3(BO_3)_4$: incommensurate magnetism

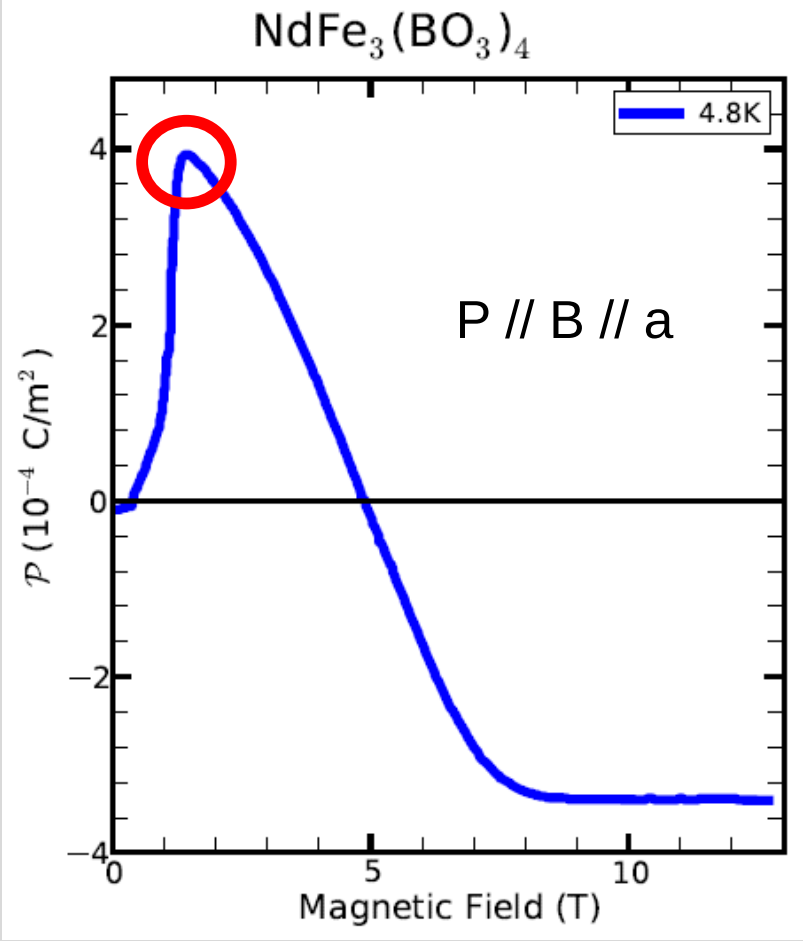
At Nd L2-edge
and Fe K-edge

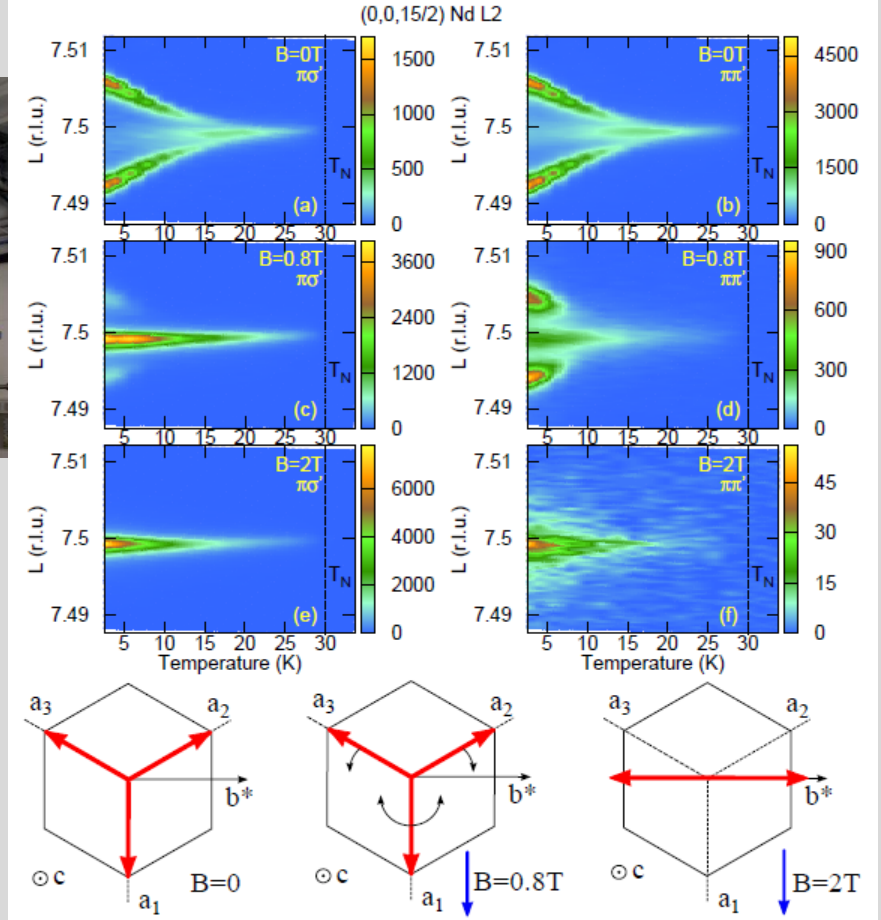




Nd magnetism
induced by Fe

$NdFe_3(BO_3)_4$: REXS in magnetic field



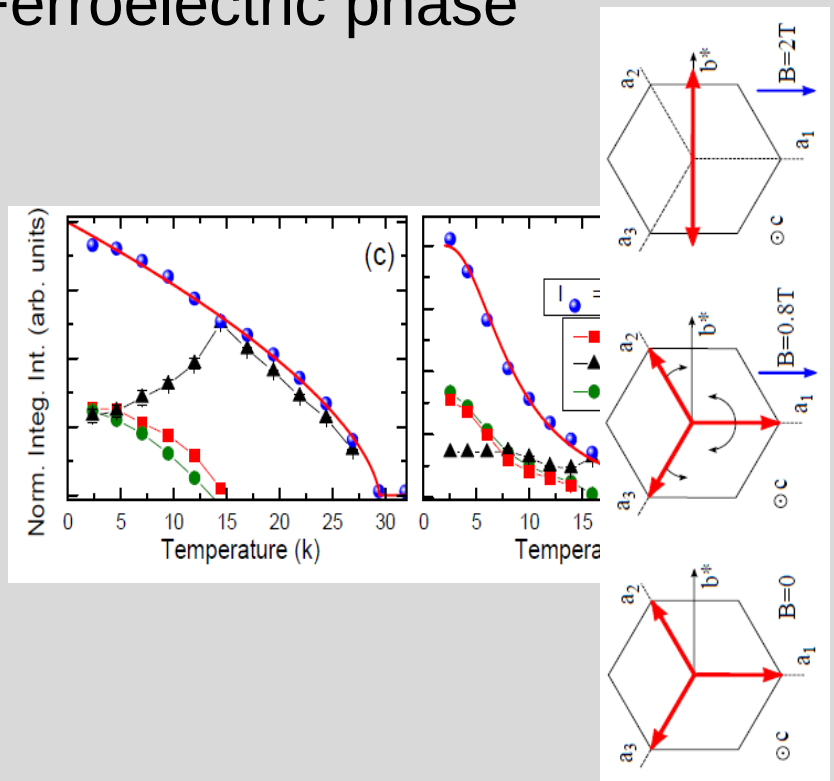


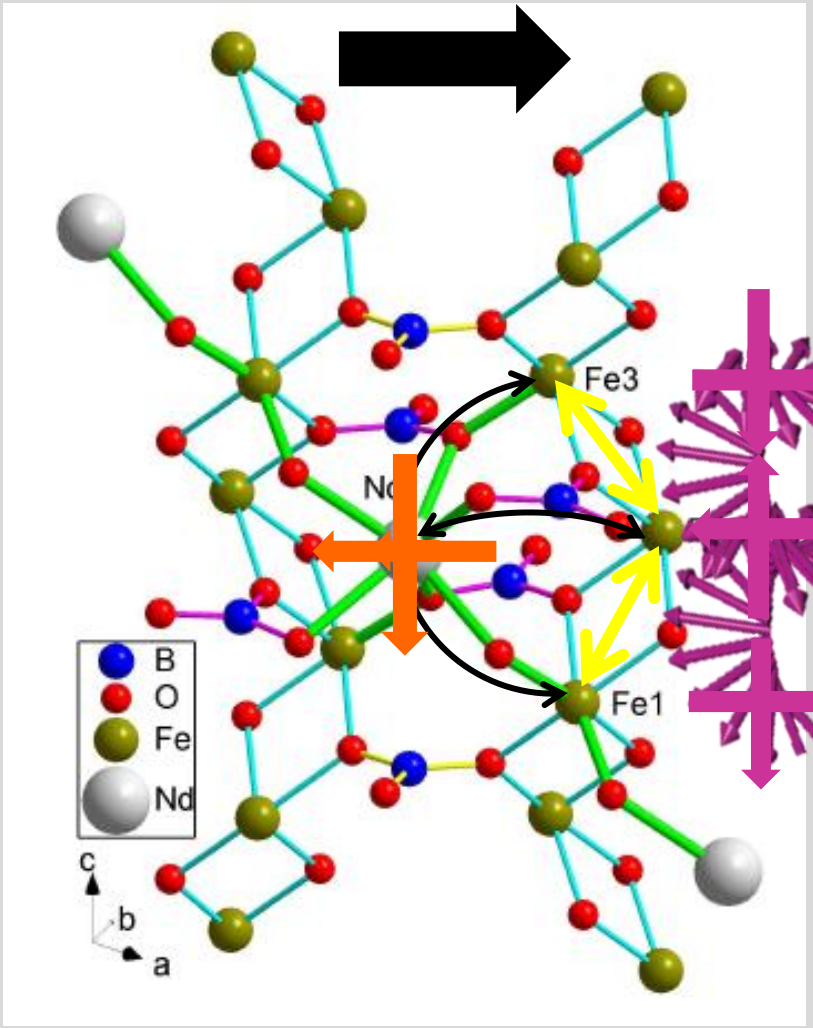
J.E. Hamann-Borrero, SP, CM et al. submitted to PRL

The polarization exists in the CM structure!

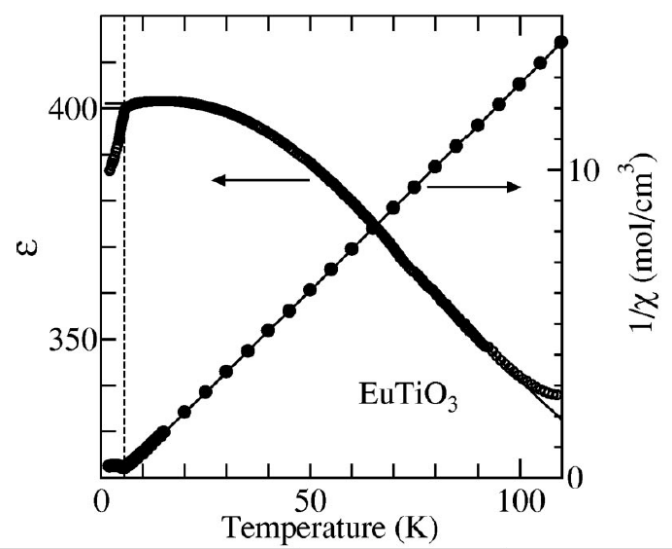
$NdFe_3(BO_3)_4$: magnetic frustration role

Magnetic frustration
alternative to
Ferroelectric phase



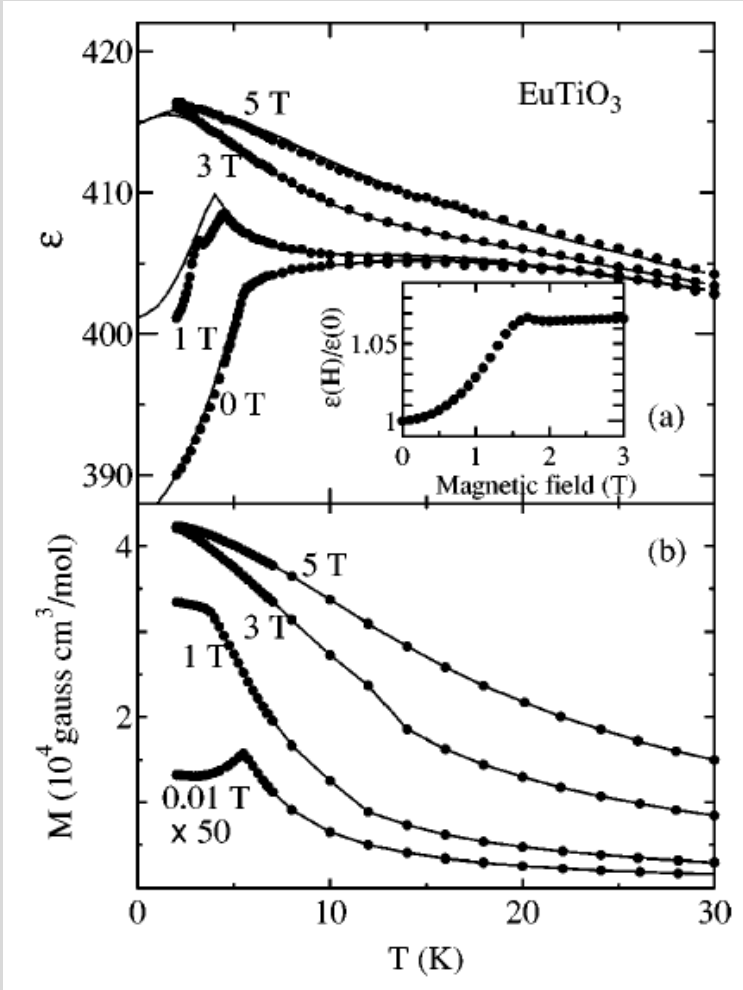


$EuTiO_3$: a peculiar ME



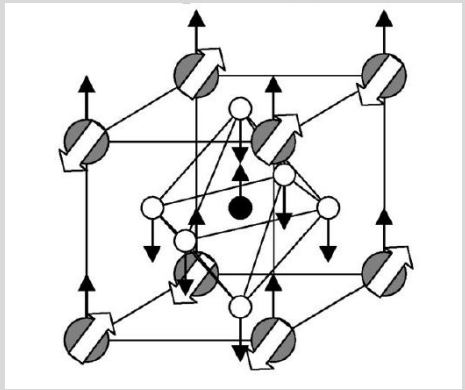
Quantum-paraelectric with ME coupling

T. Katsufuji and H. Takagi
PRB 64 (2001) 054415

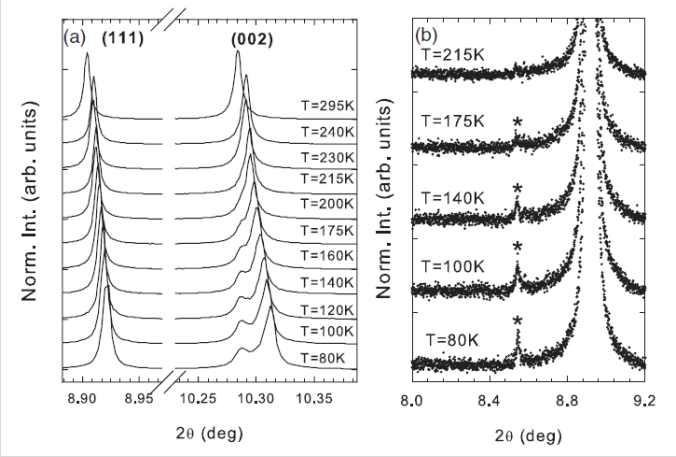


G-type AFM structure

T. R. McGuire et al.
JAP 37 (1966) 981

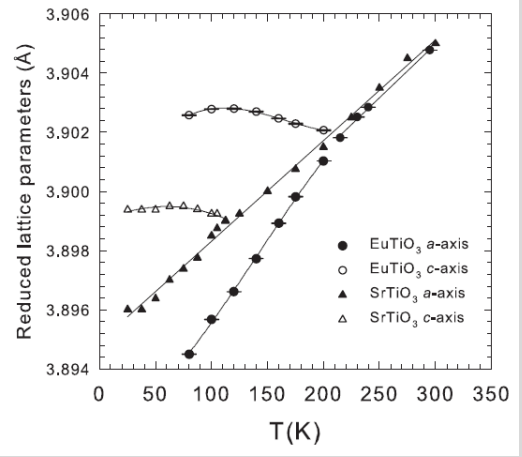


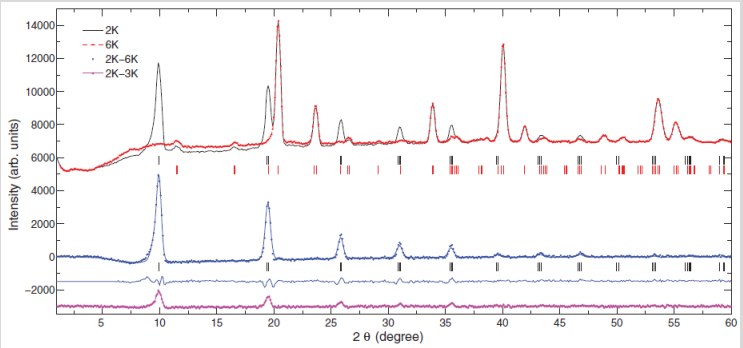
$EuTiO_3$: structures

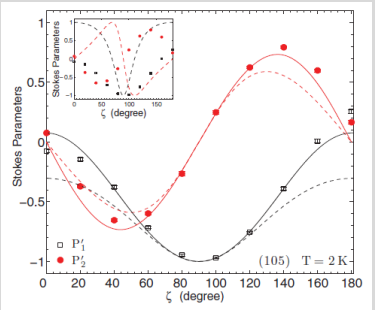


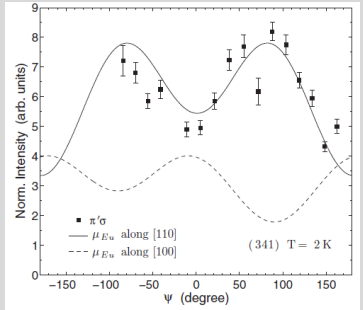
Structural phase transition
Pm-3m -> I4/mcm
XPD at ~235K

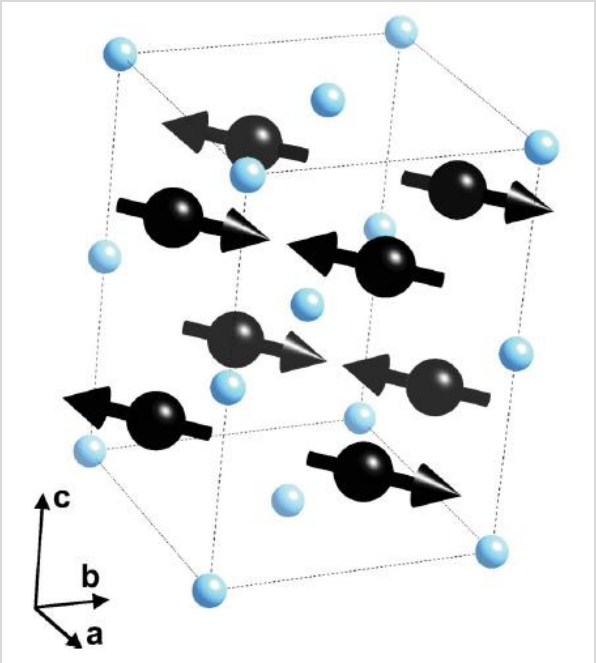
M. Allieta et al.
PRB 85 (2012) 184107









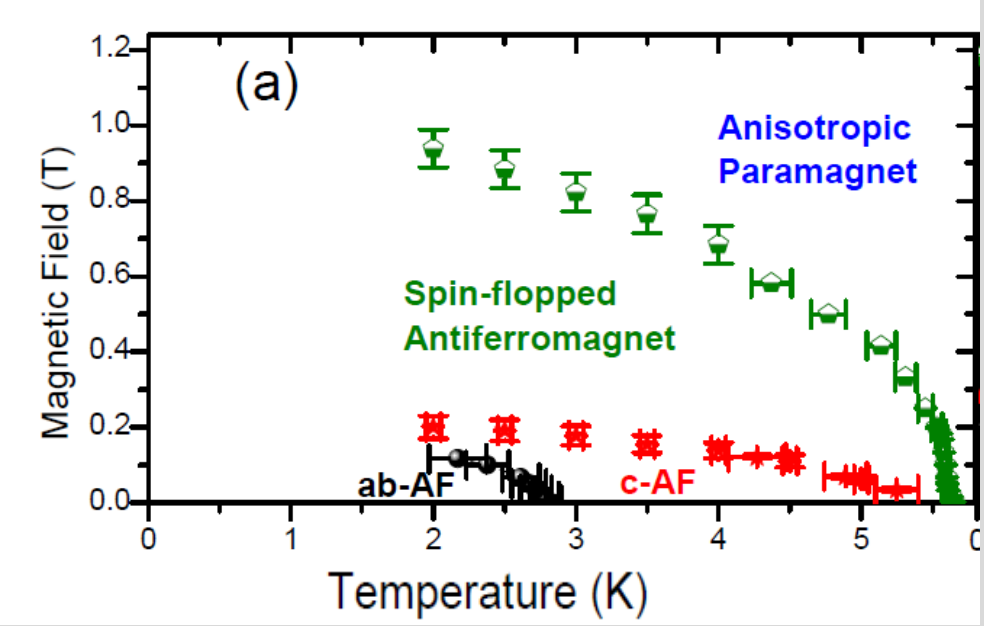


Magnetic Structure
Γ_9
μ // (110)

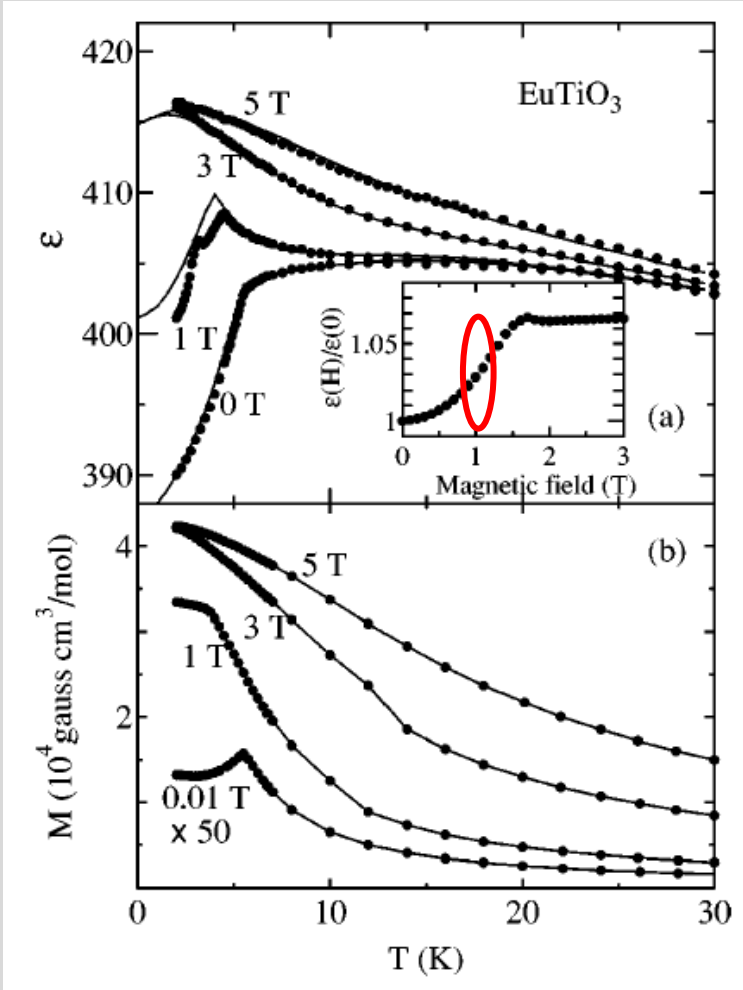
V. Scagnoli et al.
PRB 86 (2012) 094432

$EuTiO_3$: magnetic field effect

Complex magnetic phase diagram expected… relation with the measured ME effect?



A. P. Petrovic et al.
arXiv:1204.0150



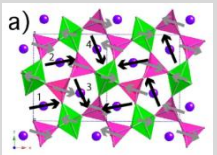
Conclusions

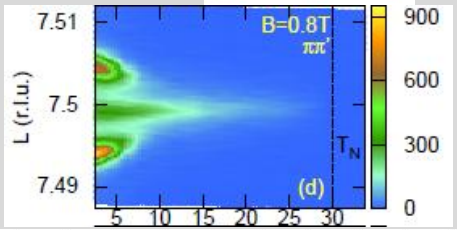
- By Resonant Elastic X-Ray Scattering (diffraction) access to important degrees of freedom is achievable (demanding data analysis)

- Key information on magnetic exchange paths, magnetoelectric and other electronic coupling mechanisms is possible (provided that a suitable ionic probe is present in the material, placed in a convenient position with respect to local symmetry elements…)

- Investigation in demanding sample environments to be performed via modern techniques (pol-scan)

- Attention should be put to the role of induced magnetism on Rare Earth ions for ME materials properties!





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- Y. Joly Inst. Néel, CNRS, Grenoble, F
- C. Detlefs ID06, ESRF, Grenoble, F
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