Neutron powder diffraction and single crystal x-ray resonant magnetic scattering studies of the doped multiferroic Tb(Bi)MnO_3

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Motivation

$TbMnO_3$

- **Orthorombic (*Pmna)***
- **Incommensurated magnetic structure below ~ 42 K**
- **Ferroelectric state below ~ 30 K**

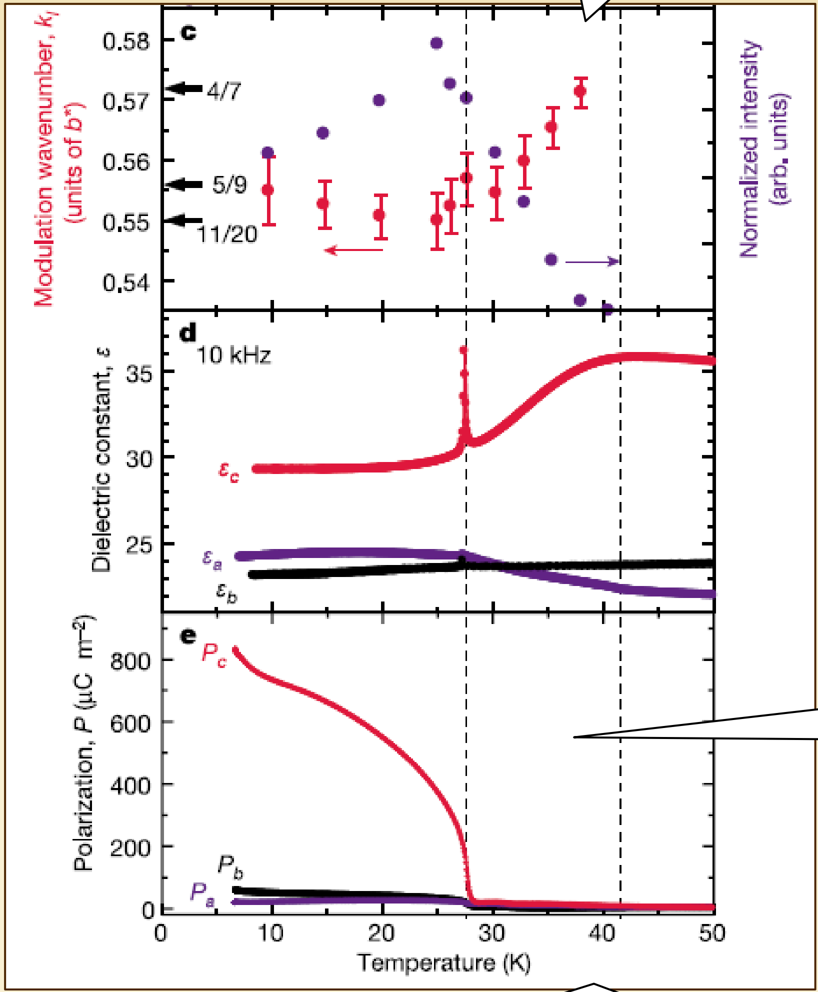
$BiMnO_3$

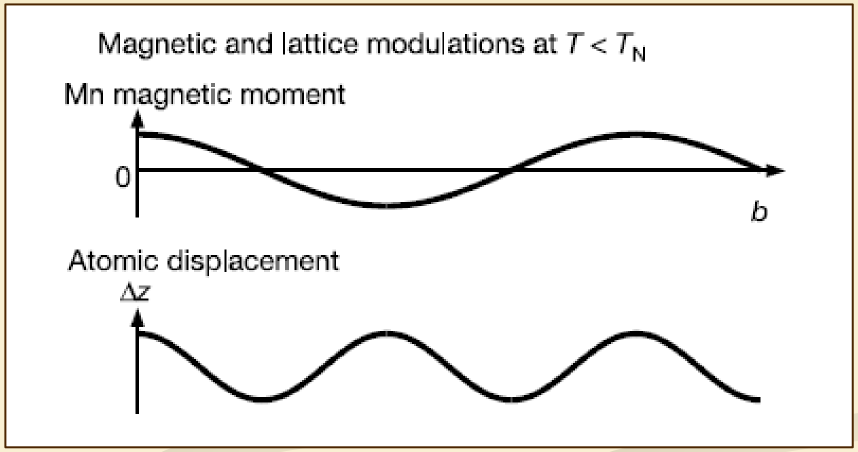
- **Monoclinic (C2-C2/c)**
- **Ferromagnetic below ~ 105 К**
- **Ferroelectric below ~ 750 К**

$Tb_{0.95}Bi_{0.05}MnO_3$?

Background

$TbMnO_3$





Polarisation depends on the magnetic field !

T. Kimura et al, Nature, 426, 6 2003

Unusual behavior in $Tb_{0.95}Bi_{0.05}MnO_3$

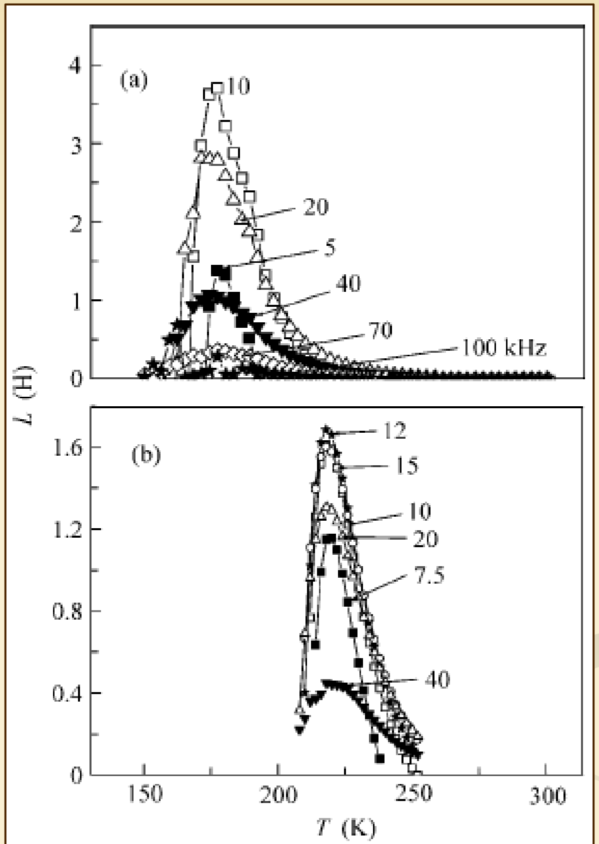
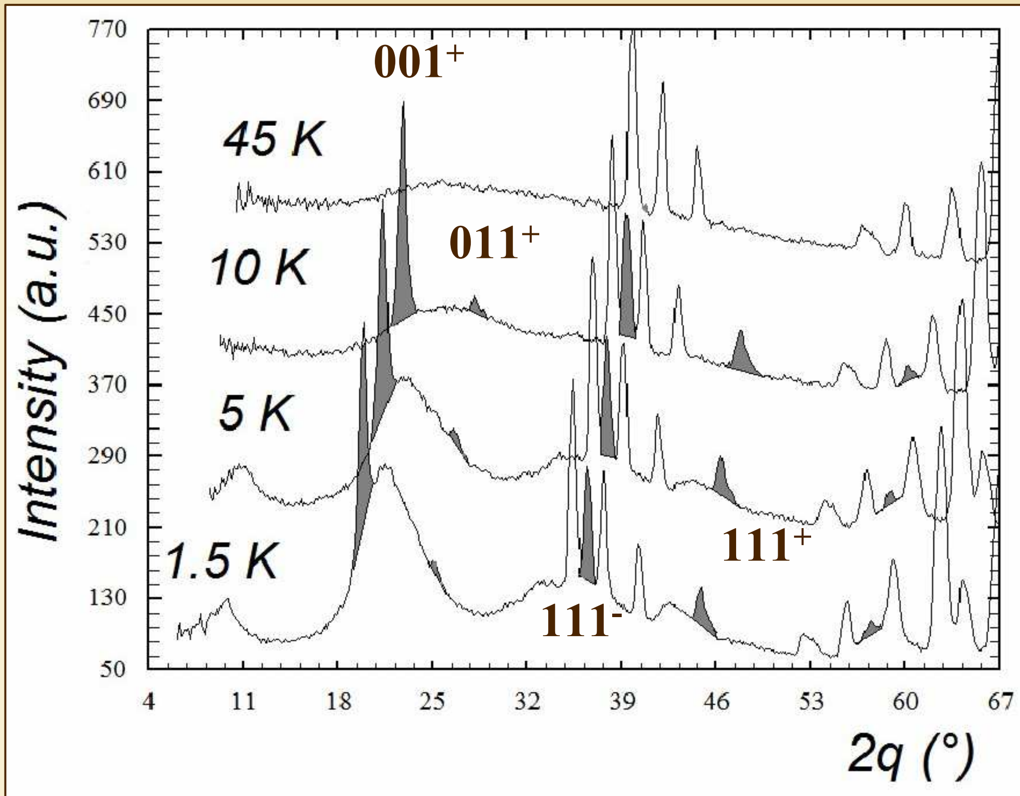


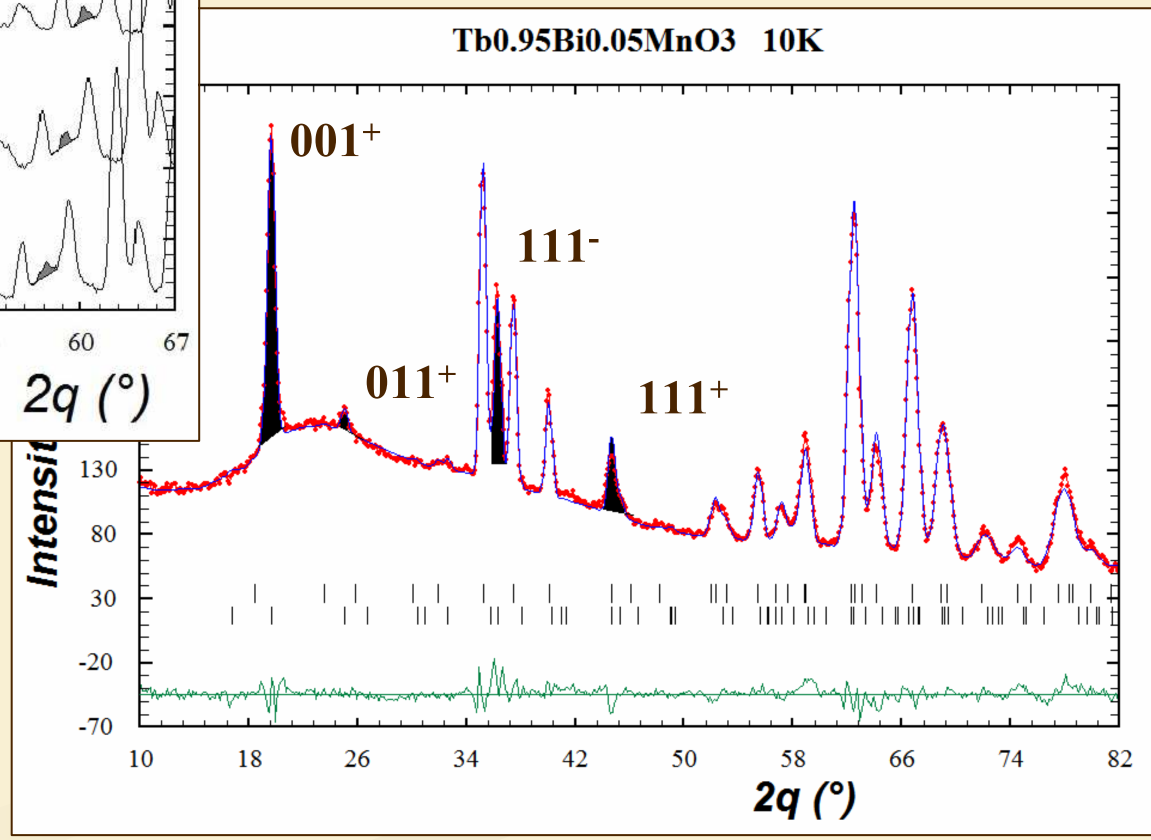
Fig. 2. Temperature dependence of the inductance for a number of the characteristic frequencies (in kilohertz) indicated near the data for (a) the initial state of the crystal before the application of the magnetic field and (b) for the case of the heating of the sample after the application and removal of the magnetic field $H = 6$ T at $T = 5$ K.

Two regimes:
low temperature and high temperature.

Inductance (L)
E. Golovenchits, V. Sanina, (JETP Letters, 84, 190, 2006)

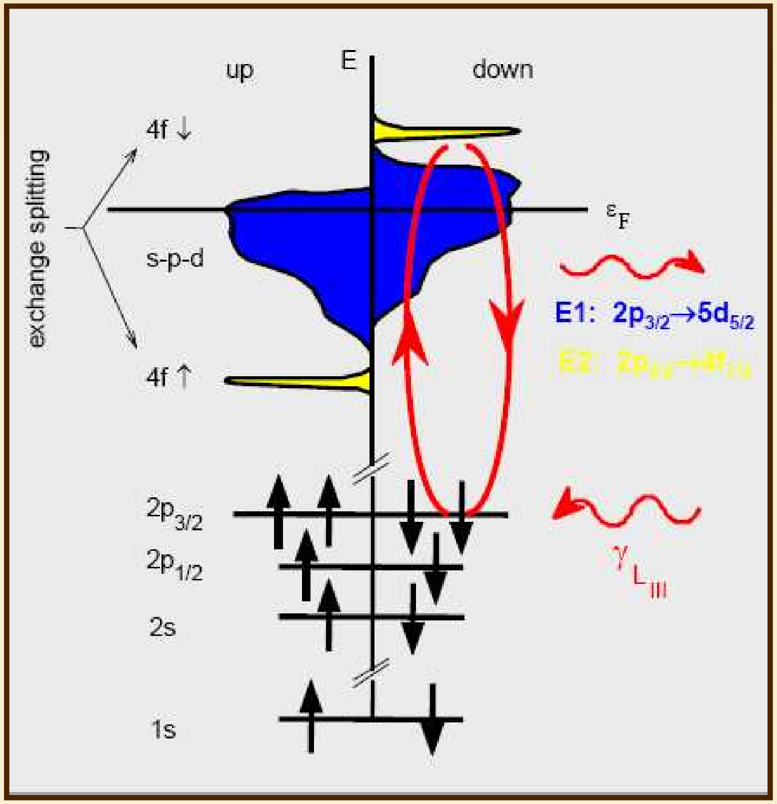
Neutron diffraction

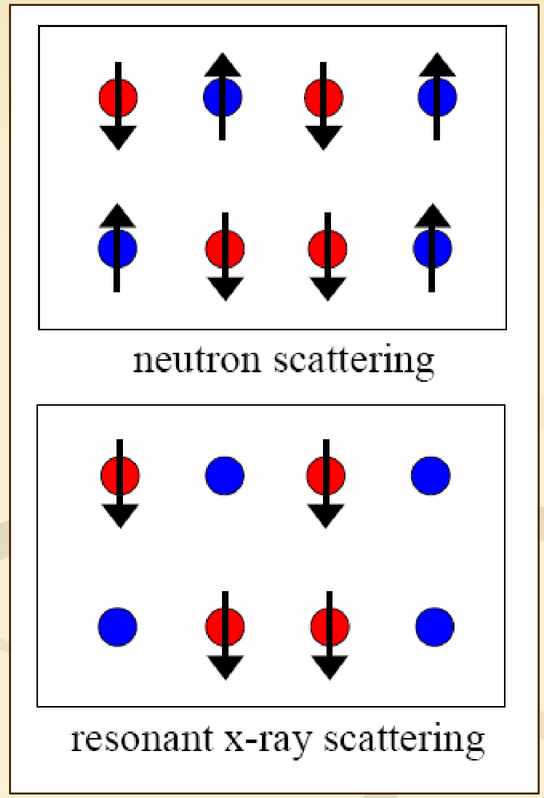




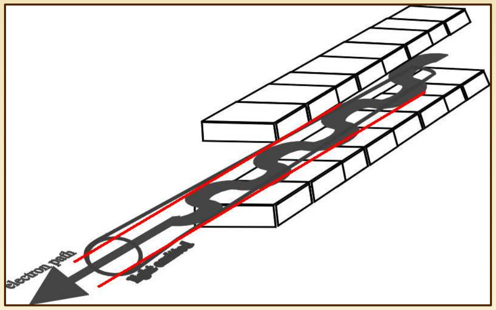
*Diffractometer E2 BENSC, **four** two-dimensional delay-line PSD 30cm x 30cm:*
resolution in horizontal 0.2° - 0.1°
in vertical 3° - 0.1°

Magnetic resonant scattering





$$\left.\frac{d\sigma}{d\Omega}\right|_{mag} \propto \left|\frac{\alpha_M / E}{(E - E_0) - i\Gamma / 2}\right|^2$$



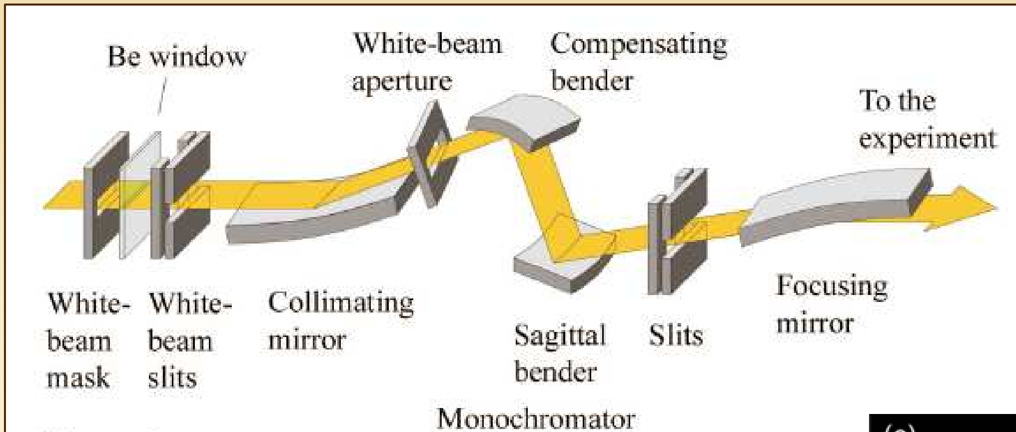
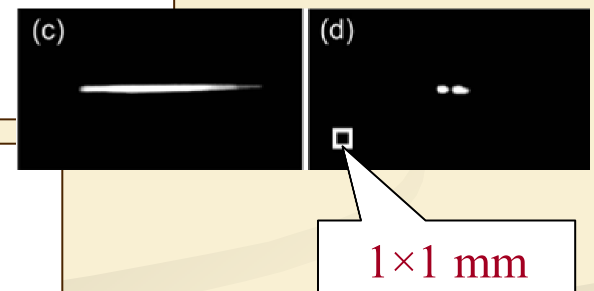
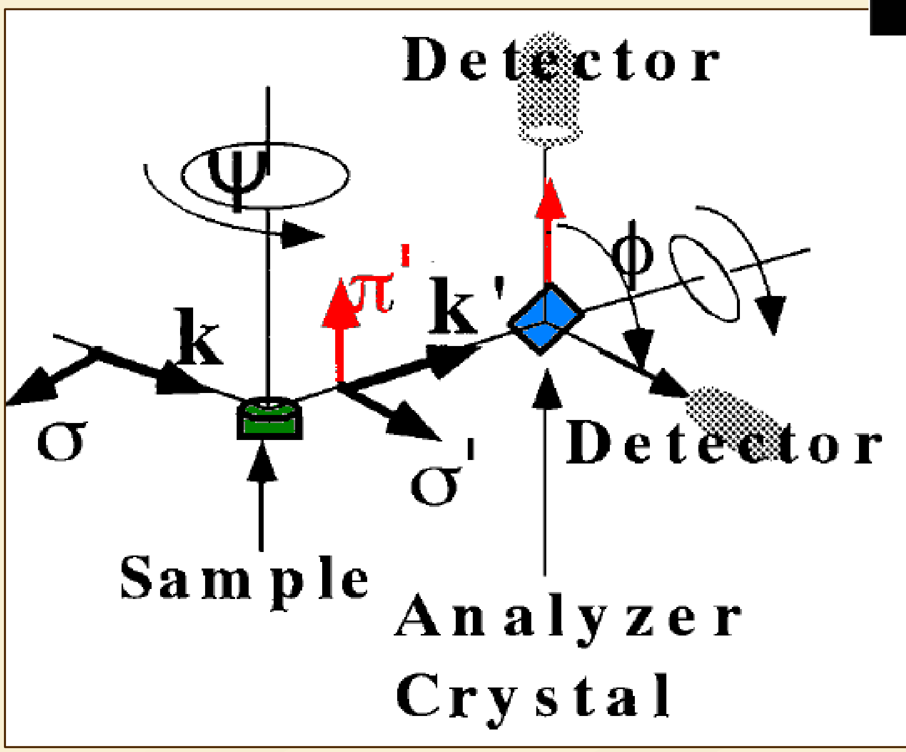
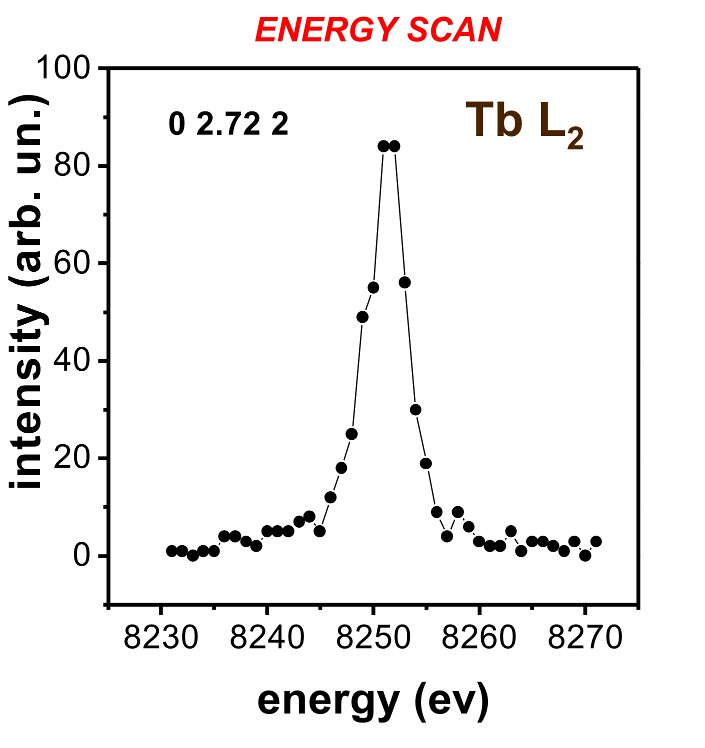
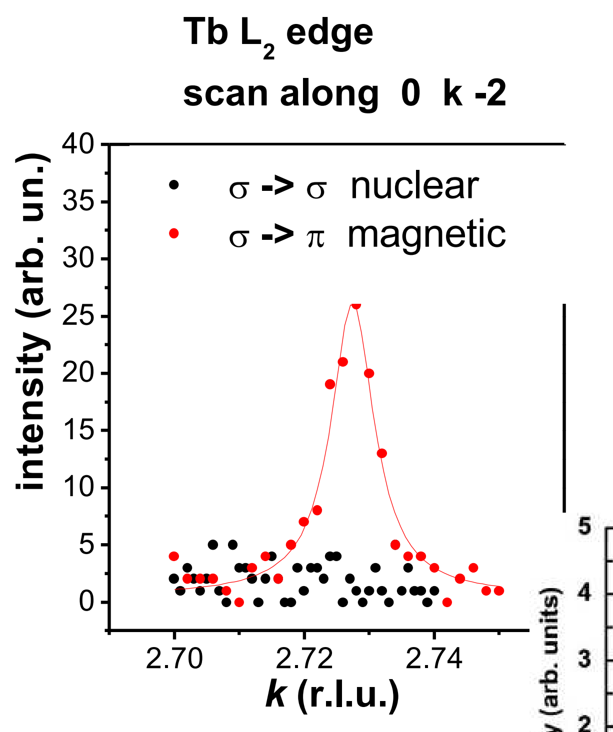


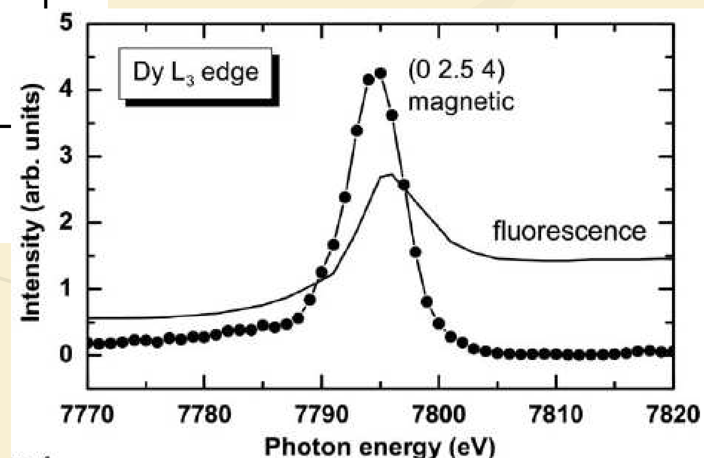
Figure 1
Overview of the beamline layout.



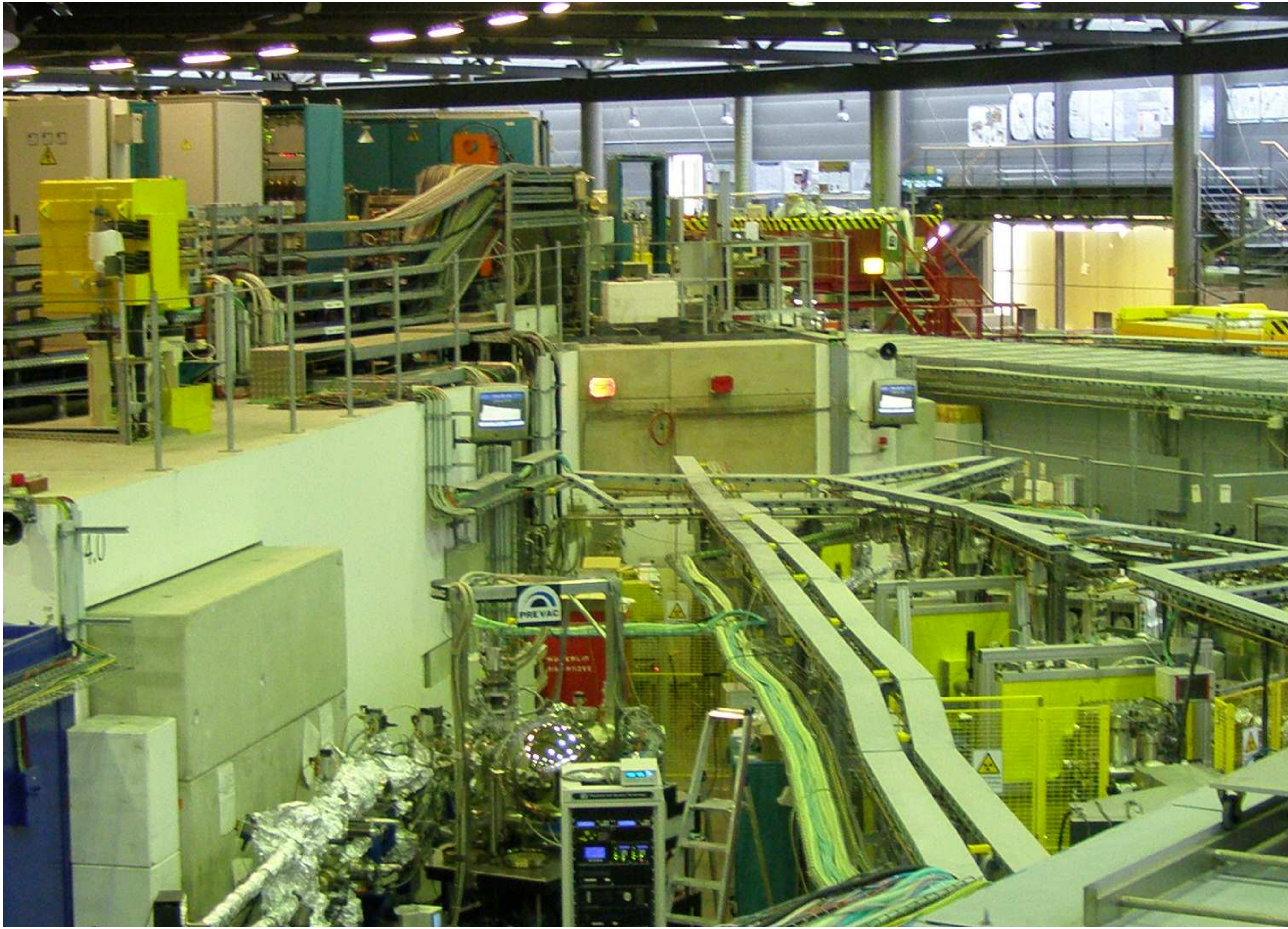








- ***Selection of the specific magnetic ion***
- ***Magnetic and nuclear scattering can be easily separated***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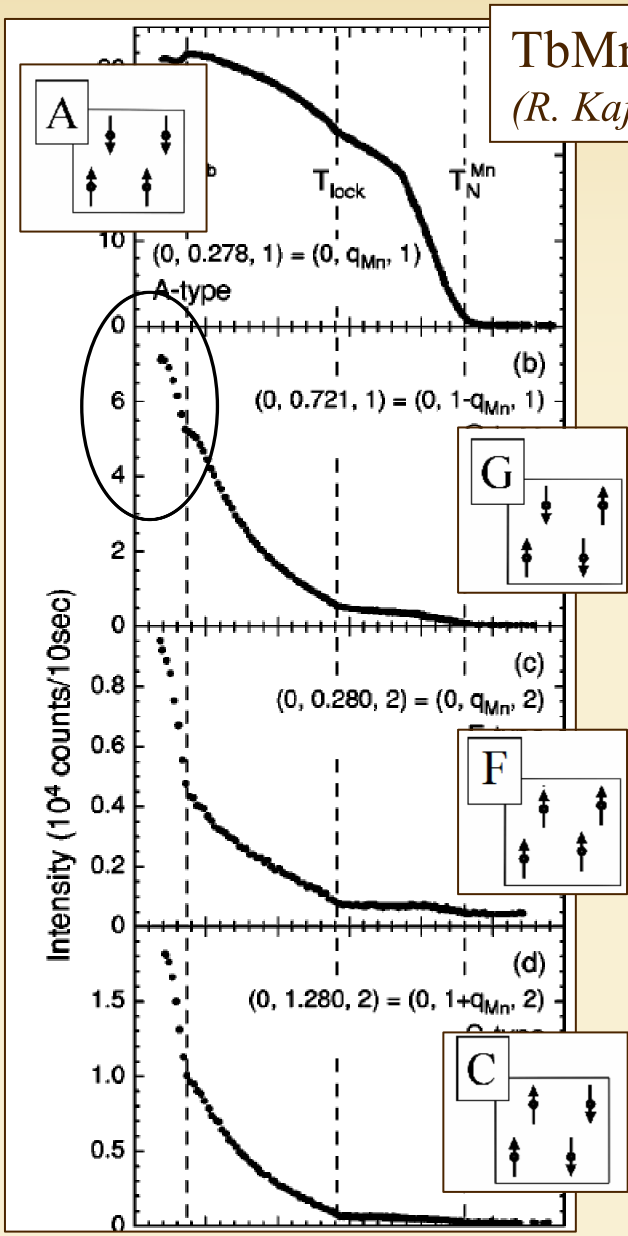
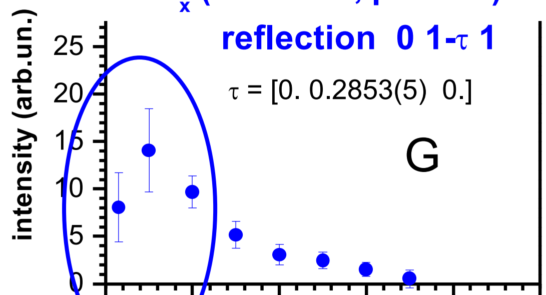
Results

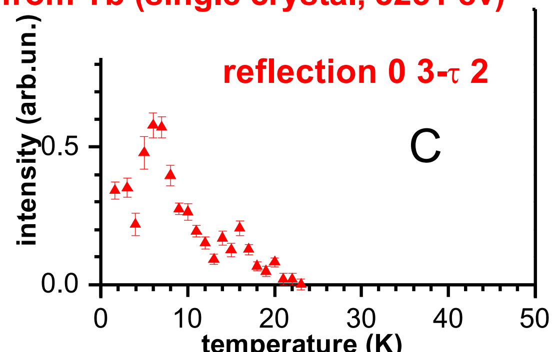
$TbMnO_3$, neutrons, single crystal,
*(R. Kajimoto at al, PRB **70**, 012401, 2004)*



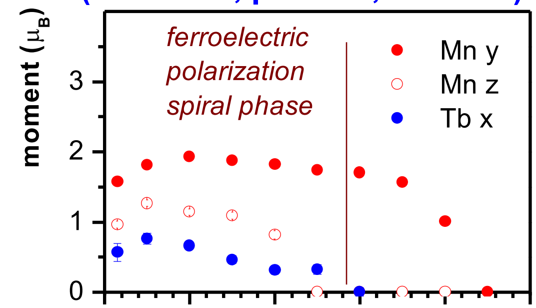
Magnetic scattering from Tb_x (neutrons, powder)



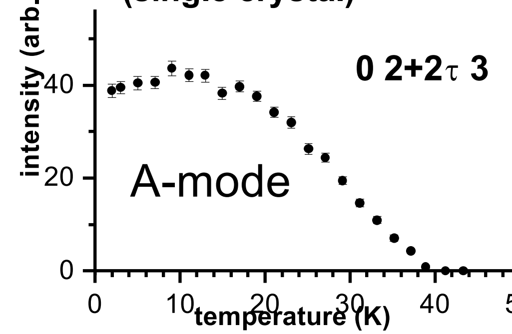
Magnetic resonant scattering from Tb (single crystal, 8251 ev)



Magnetic scattering (neutrons, powder, A-mode)

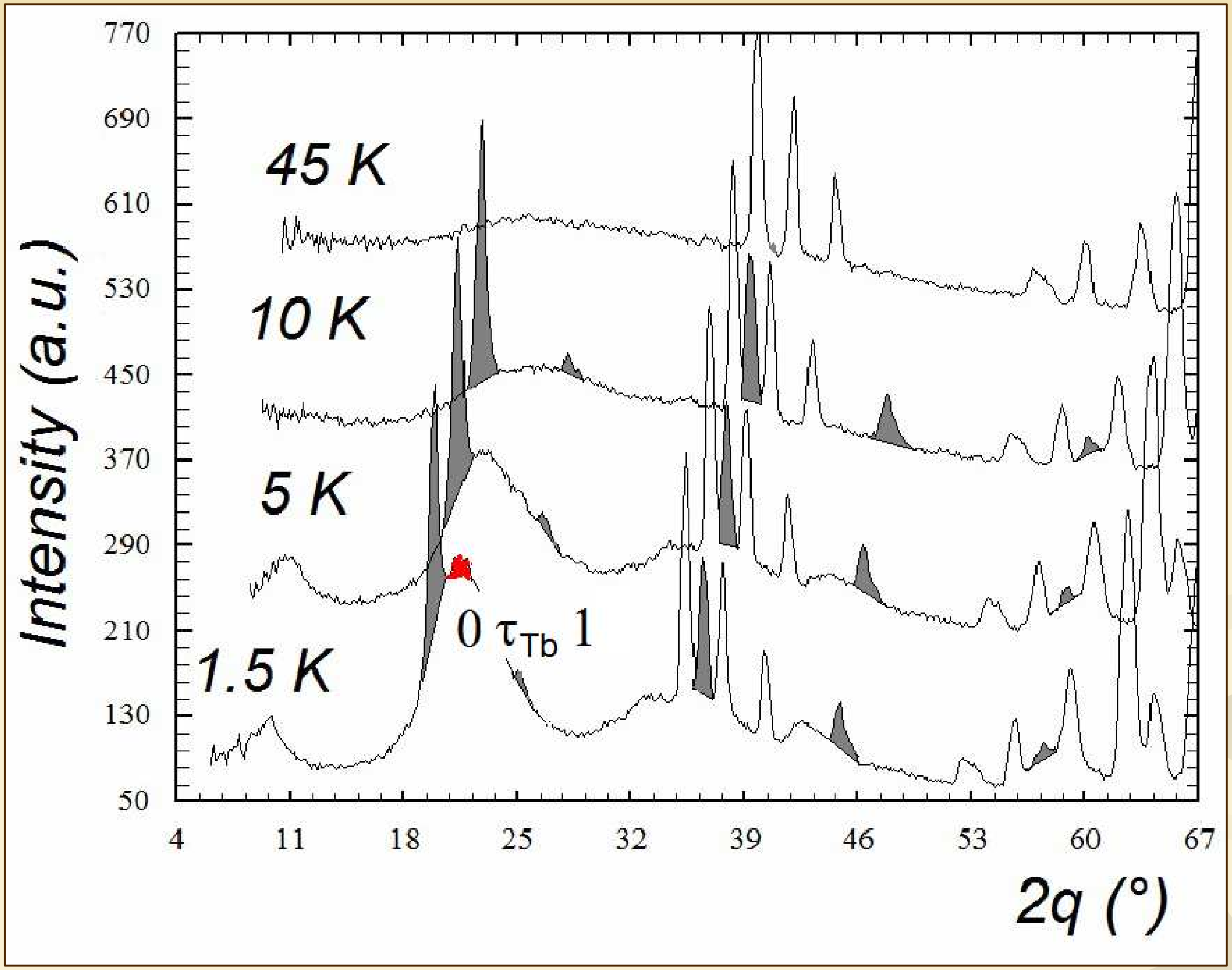


X-ray scattering (single crystal)



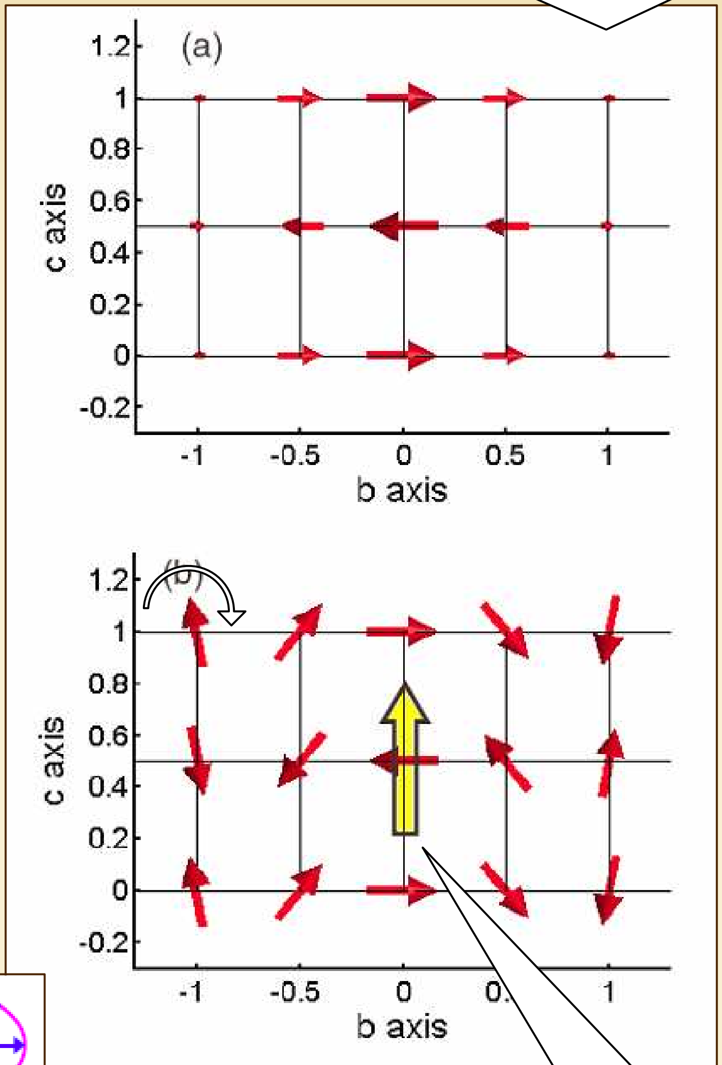
$Tb(Bi)MnO_3$

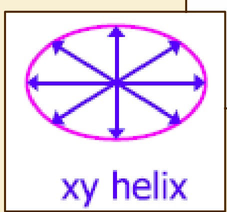
Transition from induced to intrinsic



Intrinsic Tb_x magnetic ordering appears below 5K
k_{Tb} = [0. 0.431(5) 0.]
magnetic domain size 90(8) Å

(M. Kenzelmann et al, PRL 95, 087206, 2005)





polarization

for magnetoelastic energy from symmetry reasons the only notation is

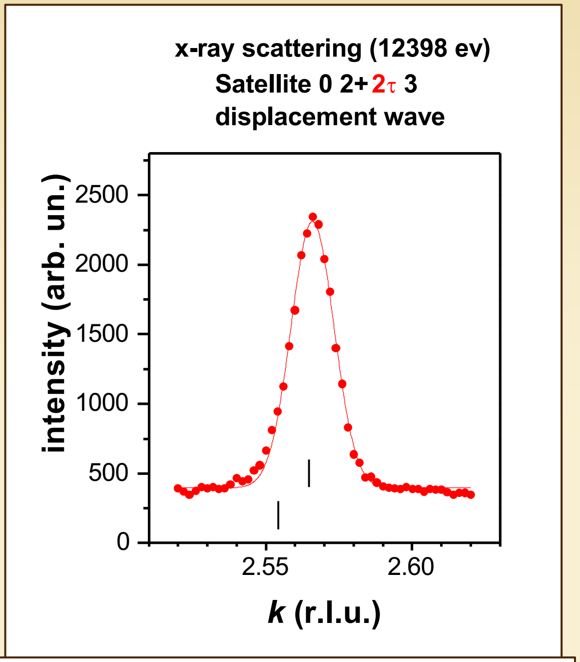
$$E_{magnetoelastic} = b_1 \cdot \varepsilon \cdot S^2 + \frac{1}{2} \cdot b_2 \cdot \varepsilon^2 + \ldots$$

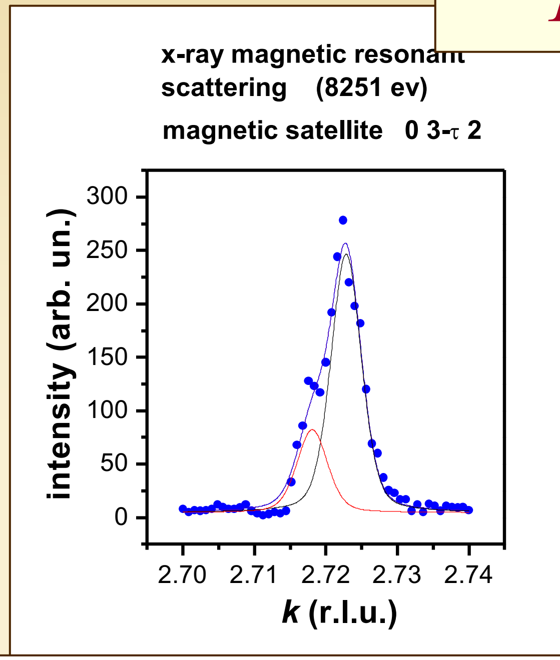
$$\frac{dE_{magnetoelastic}}{d\varepsilon} = 0, \rightarrow \qquad \varepsilon \sim (S)^2$$

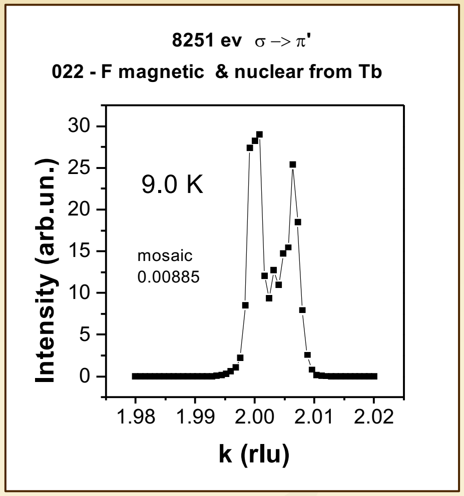
$$\tau_{nuclear} = 2\tau_{magnetic}$$

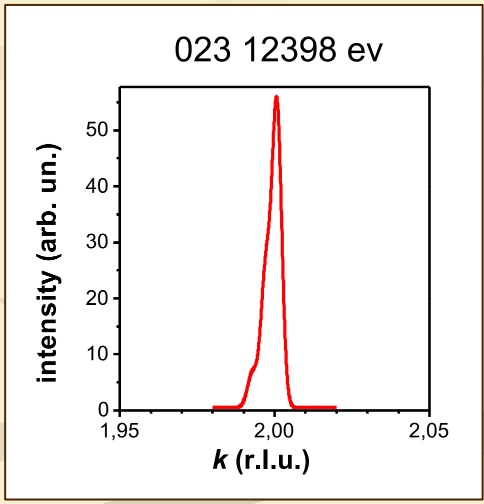
$$P \sim [\tau \times [S_i \times S_j]]$$

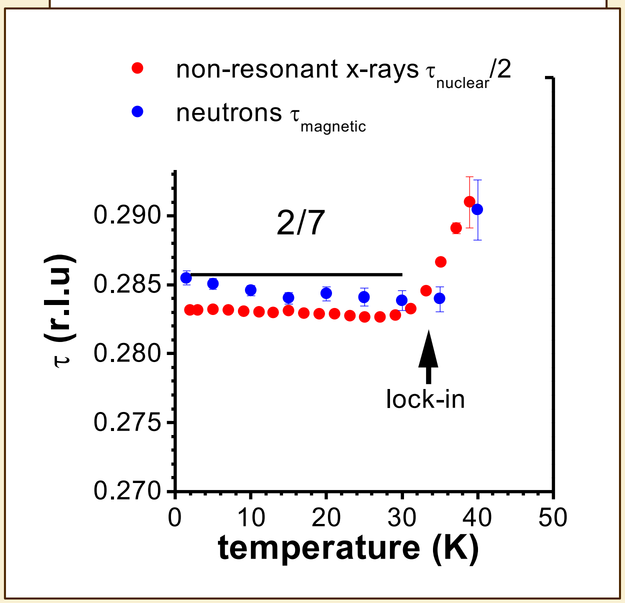
Propagation vectors

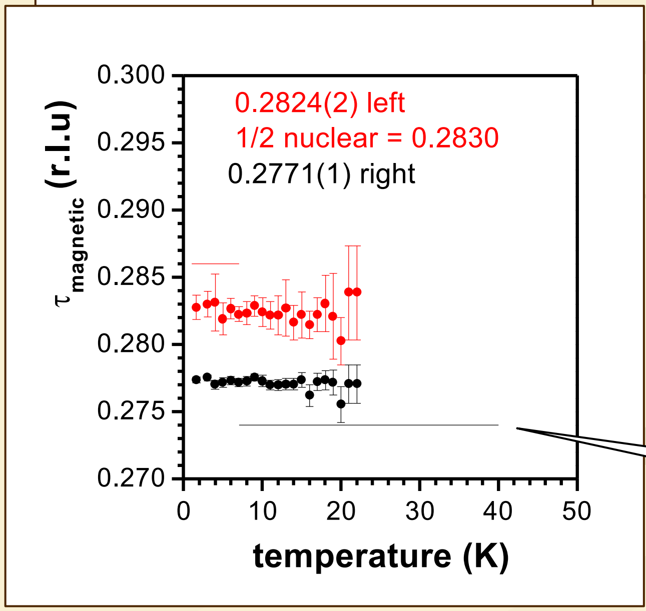












O. Prokhnenko at al, PRL ***99****, 177206, 2007*

From neutron diffraction:

Mn magnetic ordering at 5 K has $\tau_{Mn} = 0.2853(5)$***, while 2/7 = 0.2857***
Tb magnetic ordering at 1.5 K has $\tau_{Tb} = 0.431(5)$***, while 3/7 = 0.4286***

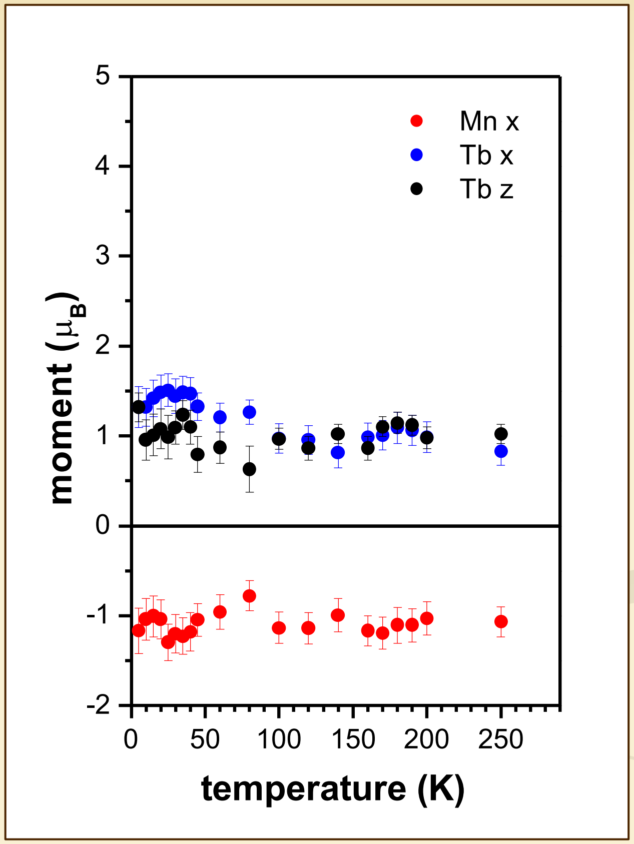
$$3\tau_{Tb} - \tau_{Mn} = 1.008(15)$$

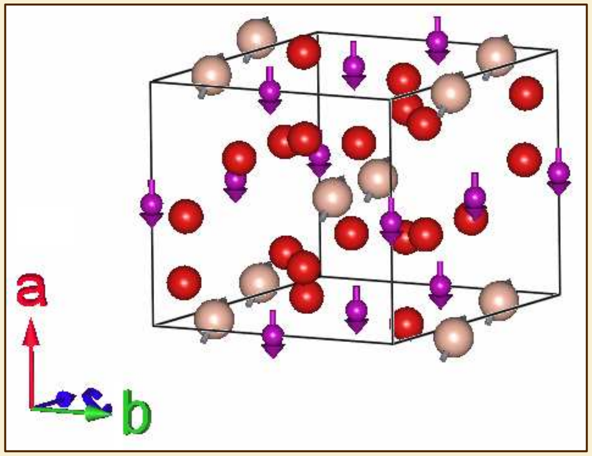
(In magnetic field this relation changes to $2\tau_{Tb} + \tau_{Mn} = 1$***)***

<u>Tb and Mn orderings remain coupled through the matching of their wave vectors</u>

*(see O. Prokhnenko at al, PRL **99,** 177206, 2007)*

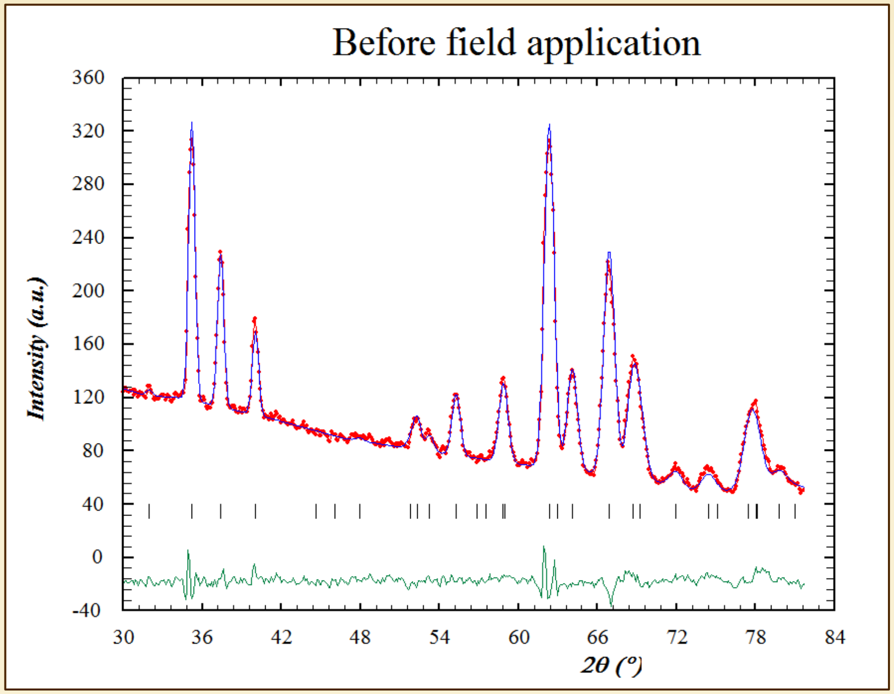
Ferromagnetic components

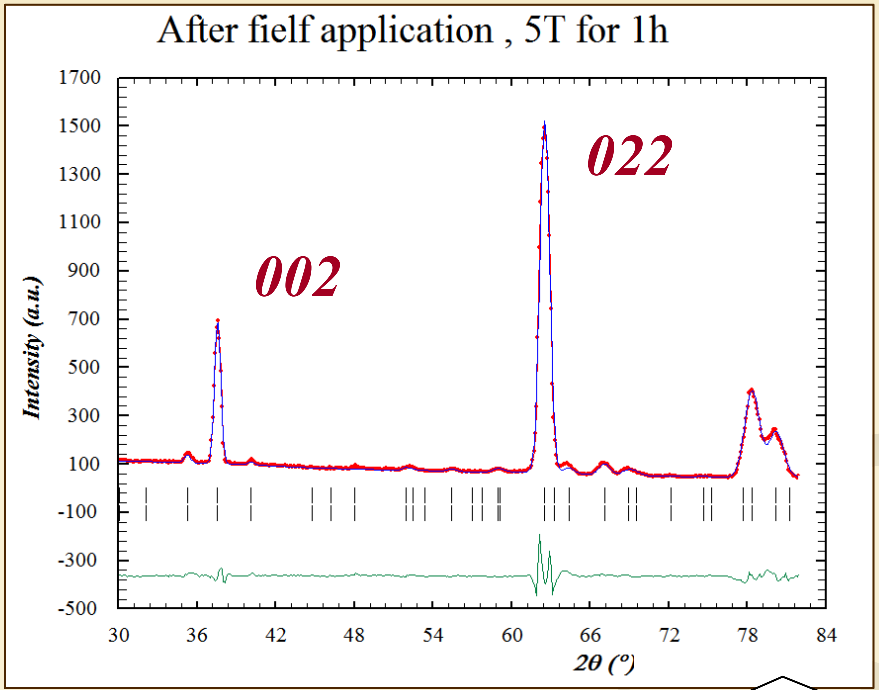


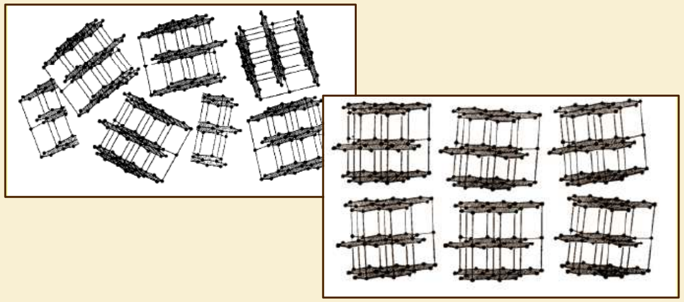


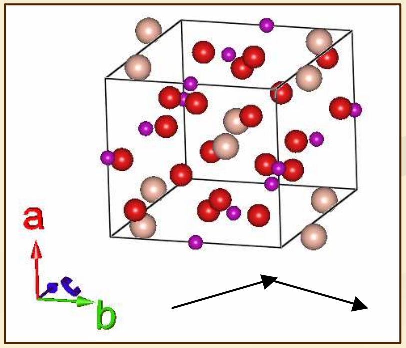
External field effects

magnetic field of 5 T at 300 K was applied,
after 1 h the field was removed,
the sample was cooling down to 5 K.









Texture along 100, 10% of volume remains non-textured

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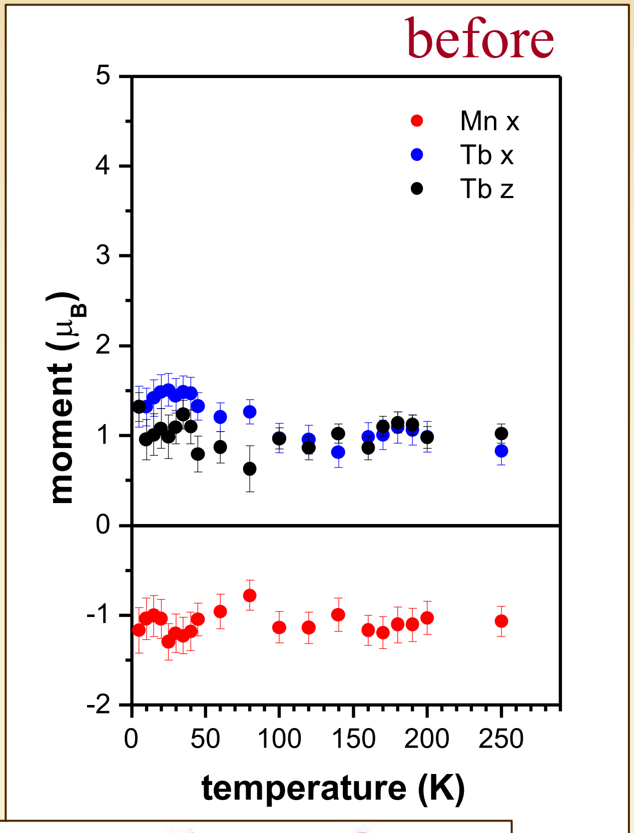
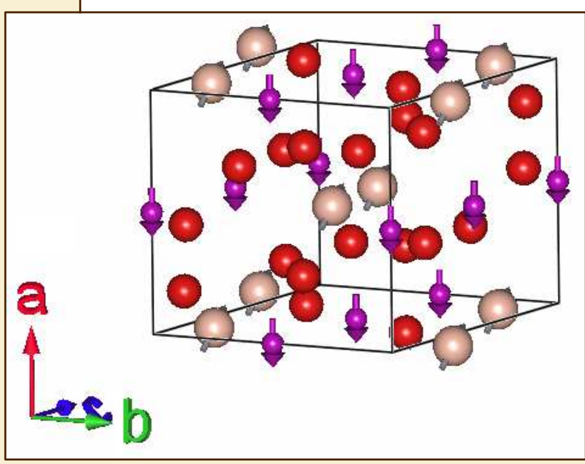
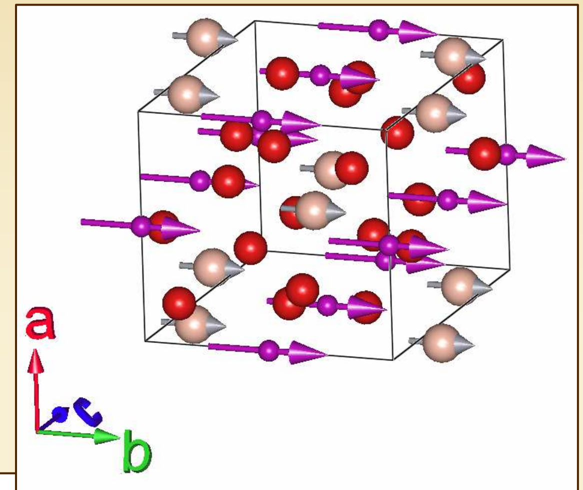
Ferromagnetic components

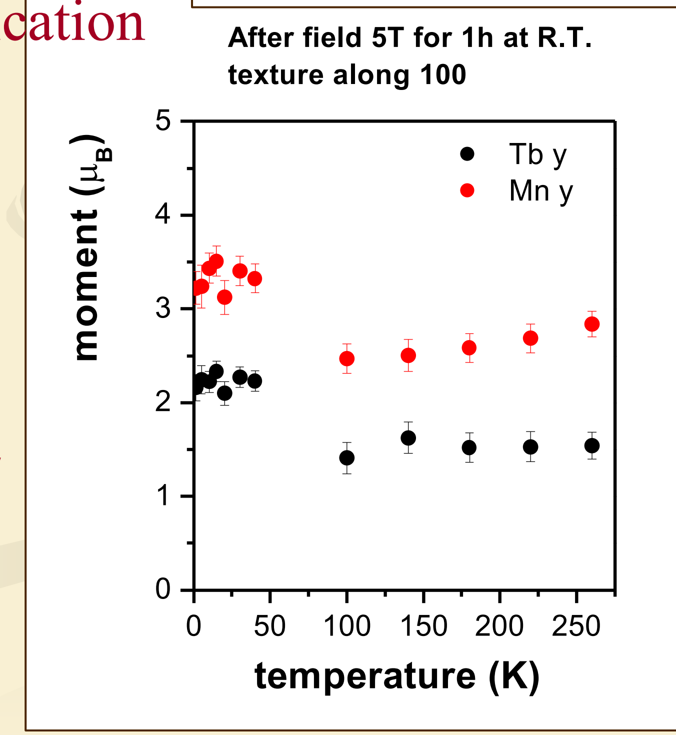




H



After field application

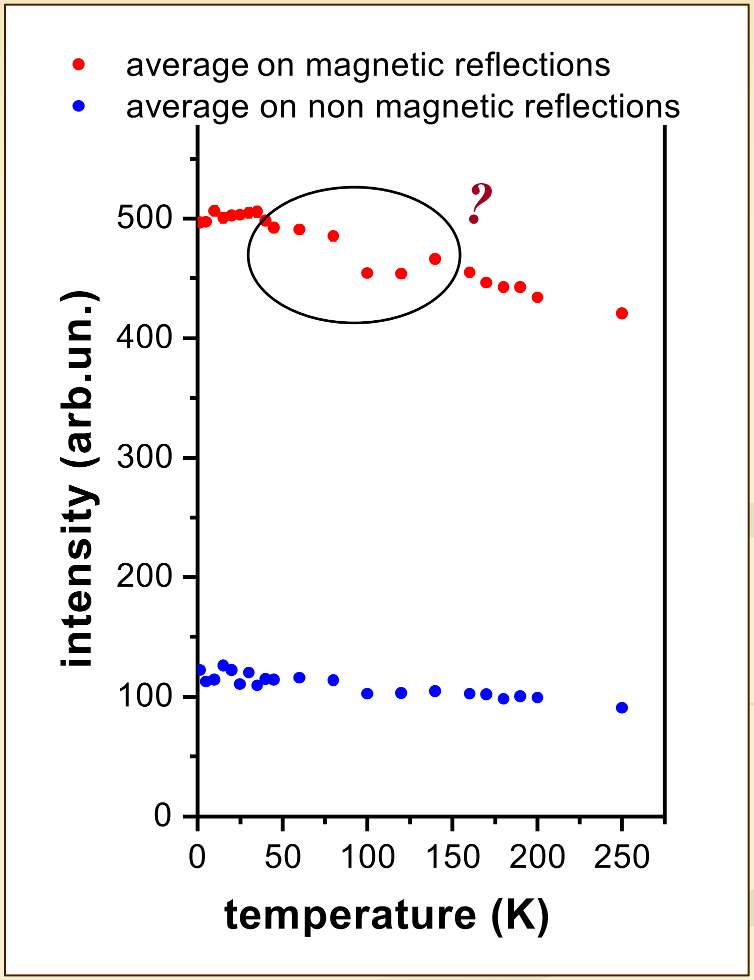


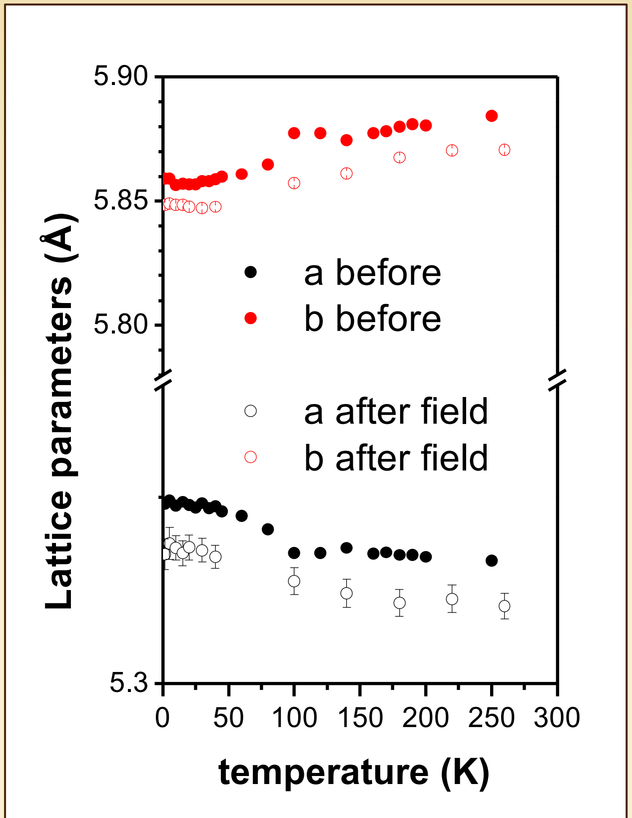
Why spin rotation?

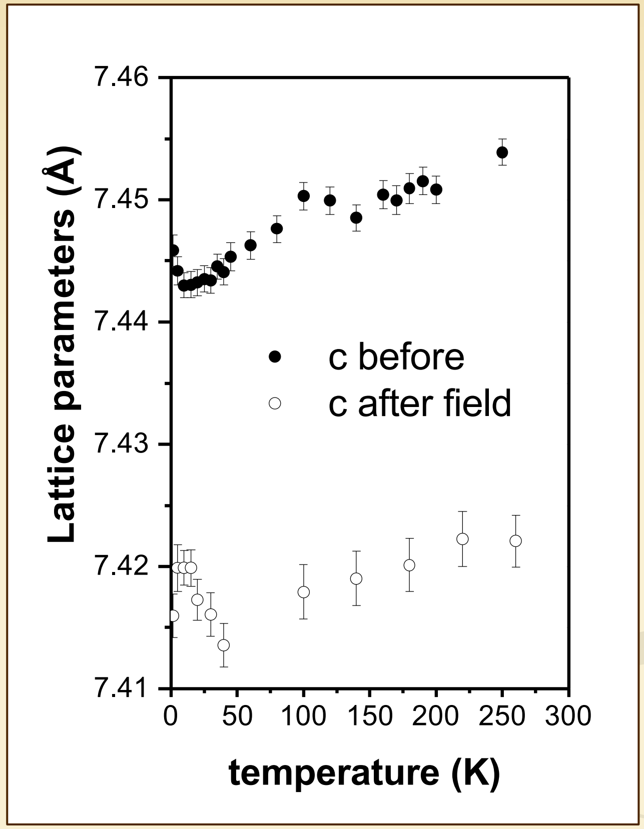
M ⊥ H ?

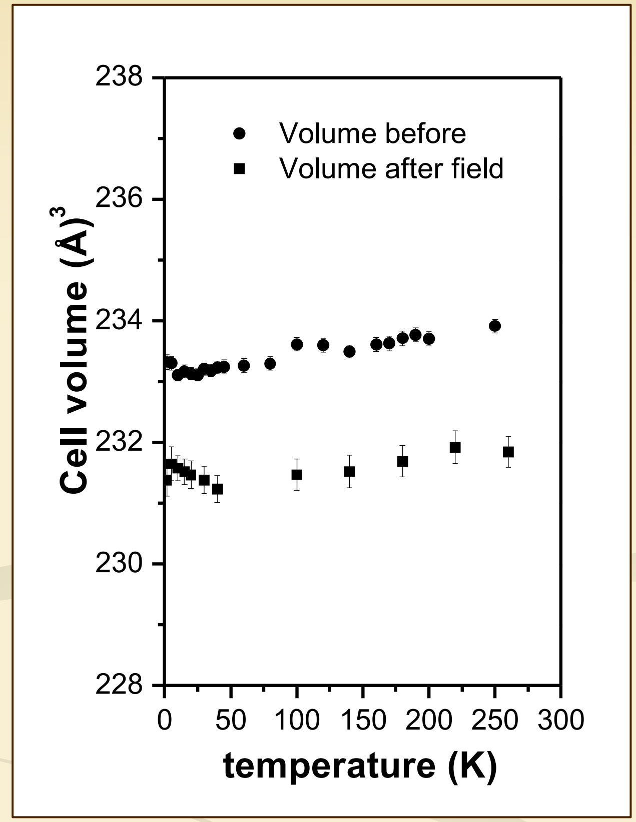
Transition with field changing?

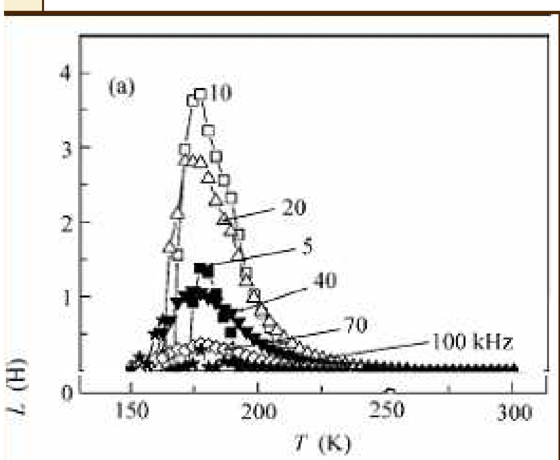
high temperature instability







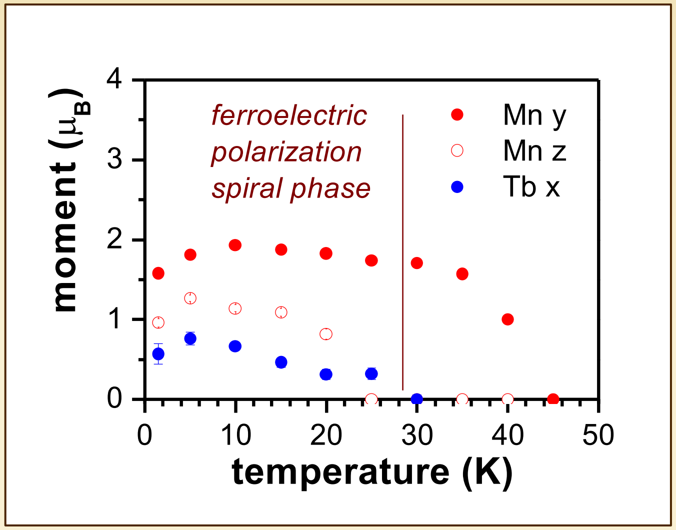




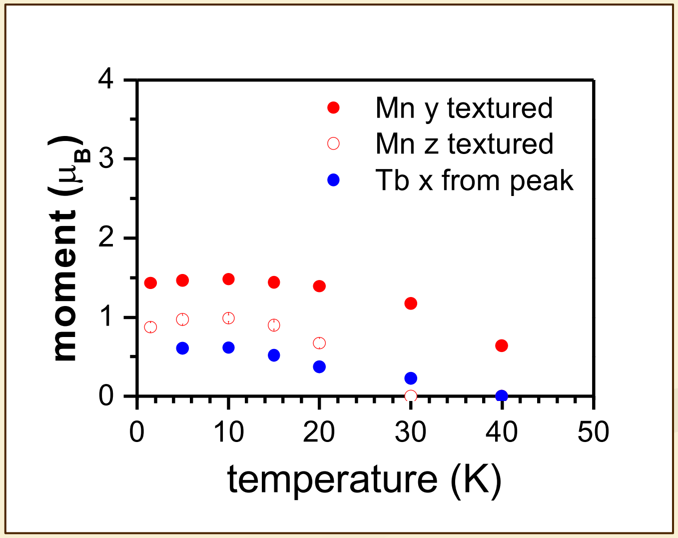
It looks like the temperature anomaly disappears after field application?

Incommensurate components

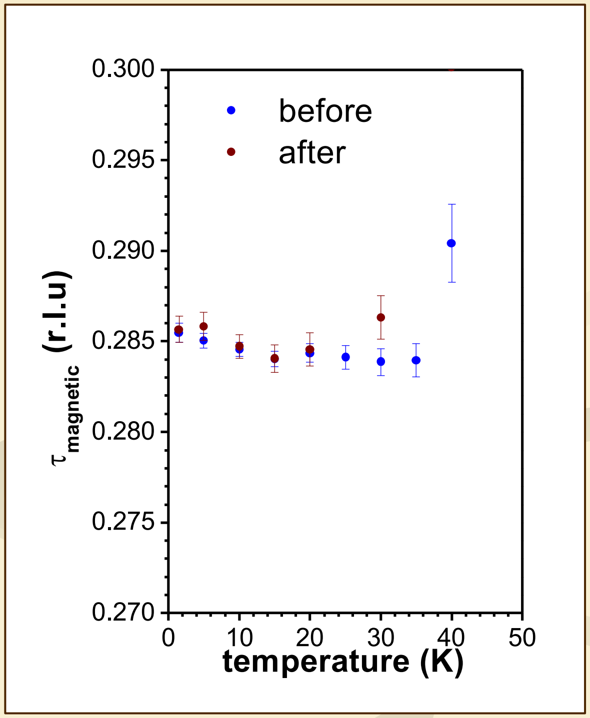
before



After field application



Propagation vector



Next steps

Studies in the magnetic fields.

What happens

- **with polarization**
- **with ferromagnetic ordering,**
- **with structure instability,**
- **non-textured component,**
- **field dependencies**

etc.

Thank for your attention