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LARMOR kick-off meeting: Magnetism and magnetic materials

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What will we use LARMOR for?

Studying the interplay between magnetic order and structure

High-resolution Larmor diffraction (1-10 Å):

- Structural domains
- Nanocrystallites in (magnetic) nanostructured materials

SANS with polarisation analysis (1-100 nm):

- Magnetic domains and nanostructures, periodic structural domains?

SESANS (30 nm – 30 μm):

- Larger scale magnetic domains, large-scale structural modulations?

It will be possible to measure smaller samples than previously possible

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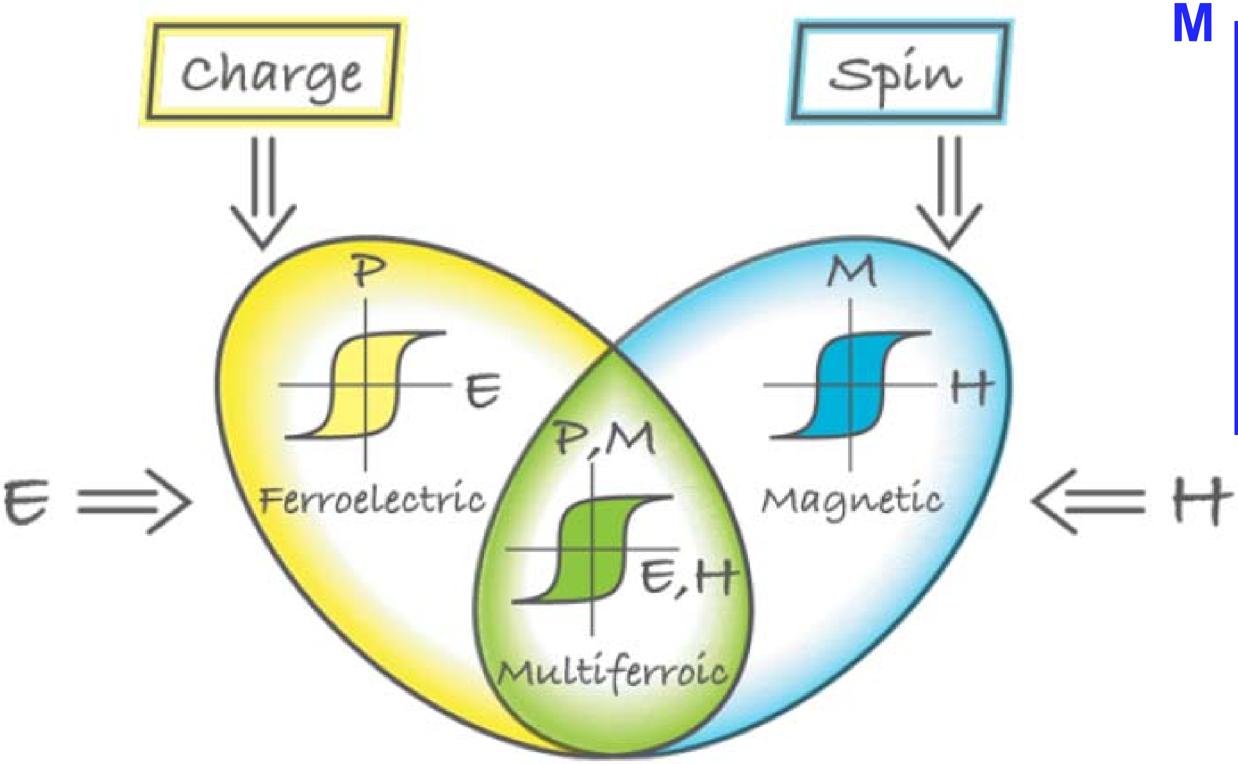
What will we use LARMOR for?

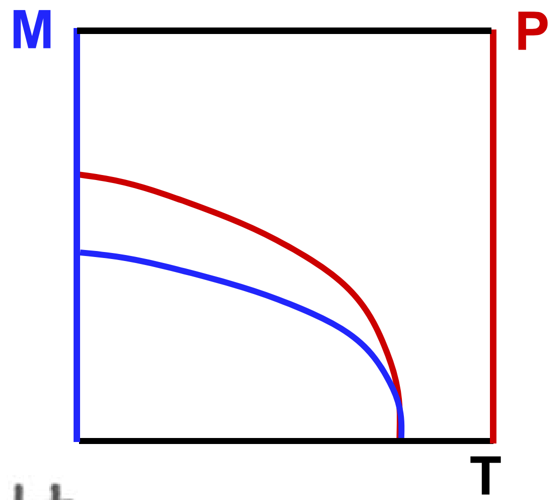
Unique capabilities of Larmor diffraction

- Study subtle (magnetically induced?) structural distortions that are beyond the best resolution of “standard” X-ray / neutron diffraction
- Determine the lattice constants and distribution of lattice constants associated with domains and nanostructured materials
- Study structural changes associated with classical or quantum phase transitions
- Gain clues as to the sizes and shapes of structural domains, density of domain walls.
- Probe the above at high / low temperature, high pressure
- The time-of-flight technique should allow the above to be probed in powders.

1. Multiferroics



D.I. Khomskii, *Physics* **2**, 20 (2009)

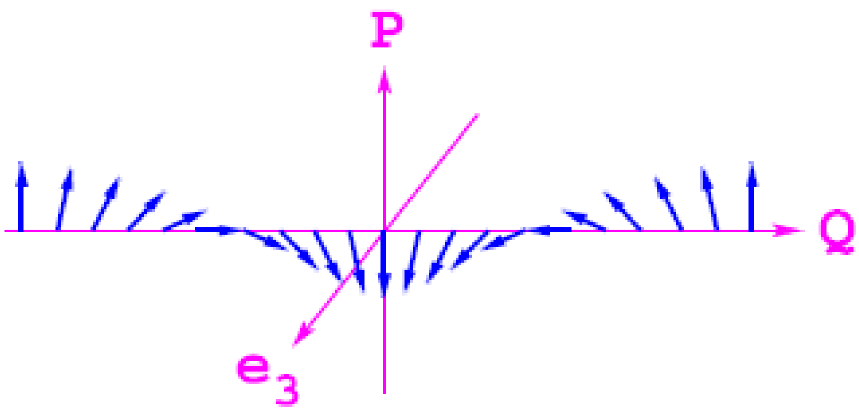


- Data storage: electric writing, magnetic reading
- Novel device architectures that mix electric and magnetic signals

1. Multiferroics: $TbMnO_3$

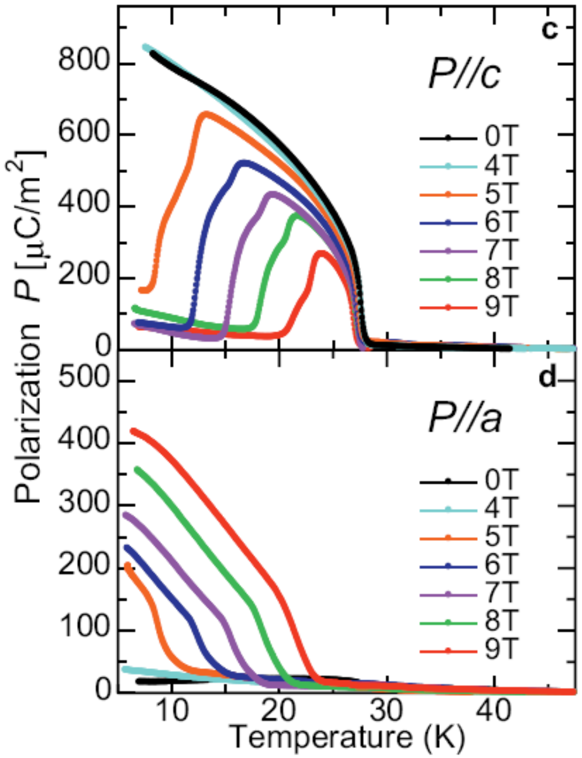
$TbMnO_3$

Antiferromagnetic



M. Mostovoy, *Phys. Rev. Lett.* **96**, 067601 (2006)

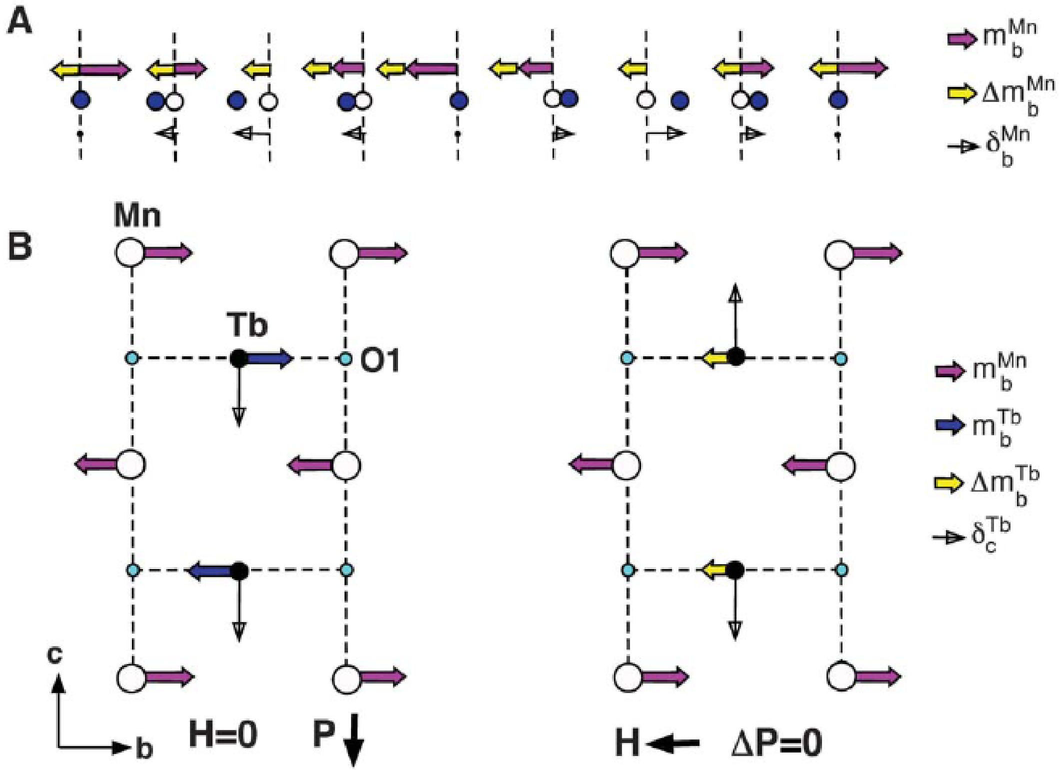
Ferroelectric



T. Kimura et al., *Nature* **426**, 55 (2003)

- Polarisation is induced by the spiral magnetic structure and can be rotated by a magnetic field.

1. Multiferroics: $TbMnO_3$

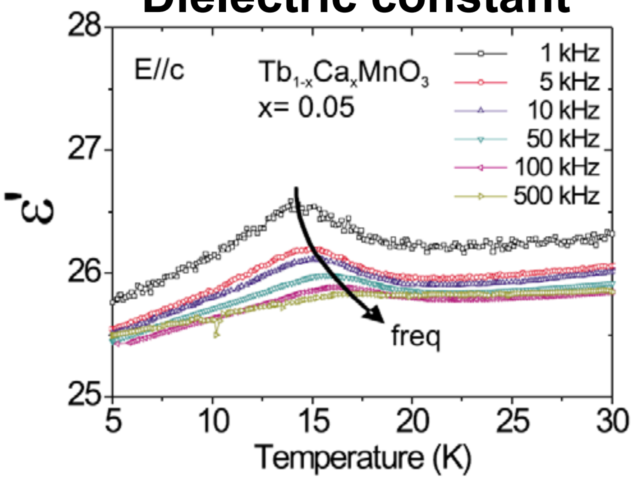


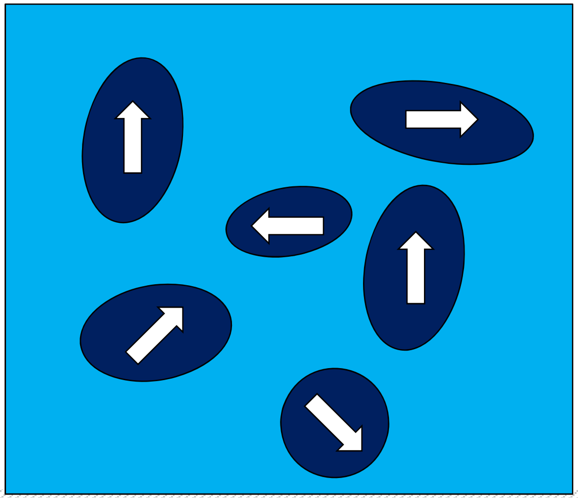
H.C. Walker et al., *Science* **333**, 1273 (2011)

- Magnetically induced atomic displacements in $TbMnO_3$ are of the order 50 fm/T.
- Larmor diffraction promises to be a convenient way of studying such tiny magnetically-induced structural distortions.

1. Multiferroics: $Tb_{1-x}Ca_xMnO_3$

Dielectric constant





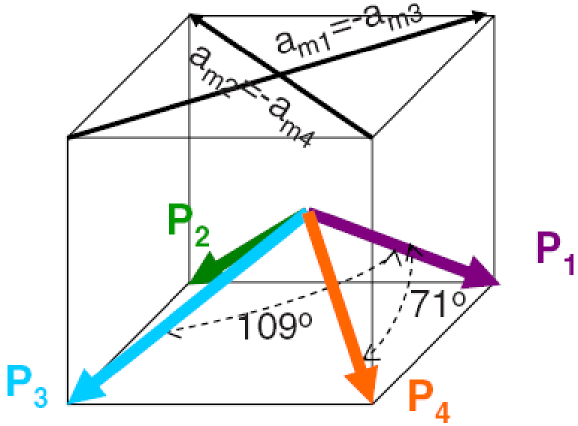
Polar nanoregions (PNR) in non-polar bulk

Larmor diffraction

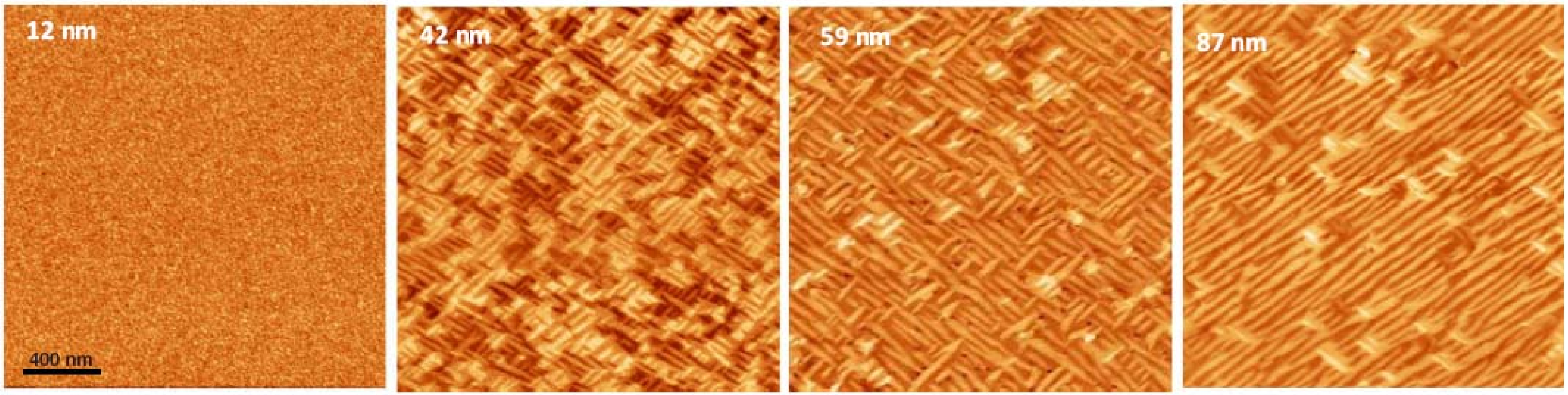
- Determine the magnitude of the magnetically induced structural distortion
- Determine the lattice constants and distribution of lattice constants in the bulk region and in the PNR
- Measure evolution of lattice as a function of temperature and doping
- What is the nature of the PNR?
- How homogeneous is the structure?

N. Mufti et al., *Phys. Rev. B* **78**, 024109 (2008)

1. Multiferroics: $BiFeO_3$ thin films



Piezo force microscopy images of $BiFeO_3$ films on $SrRuO_3/SrTiO_3$ showing ferroelectric domains



C.J.M. Daumont et al., *Phys. Rev. B* **81**, 144115 (2010)

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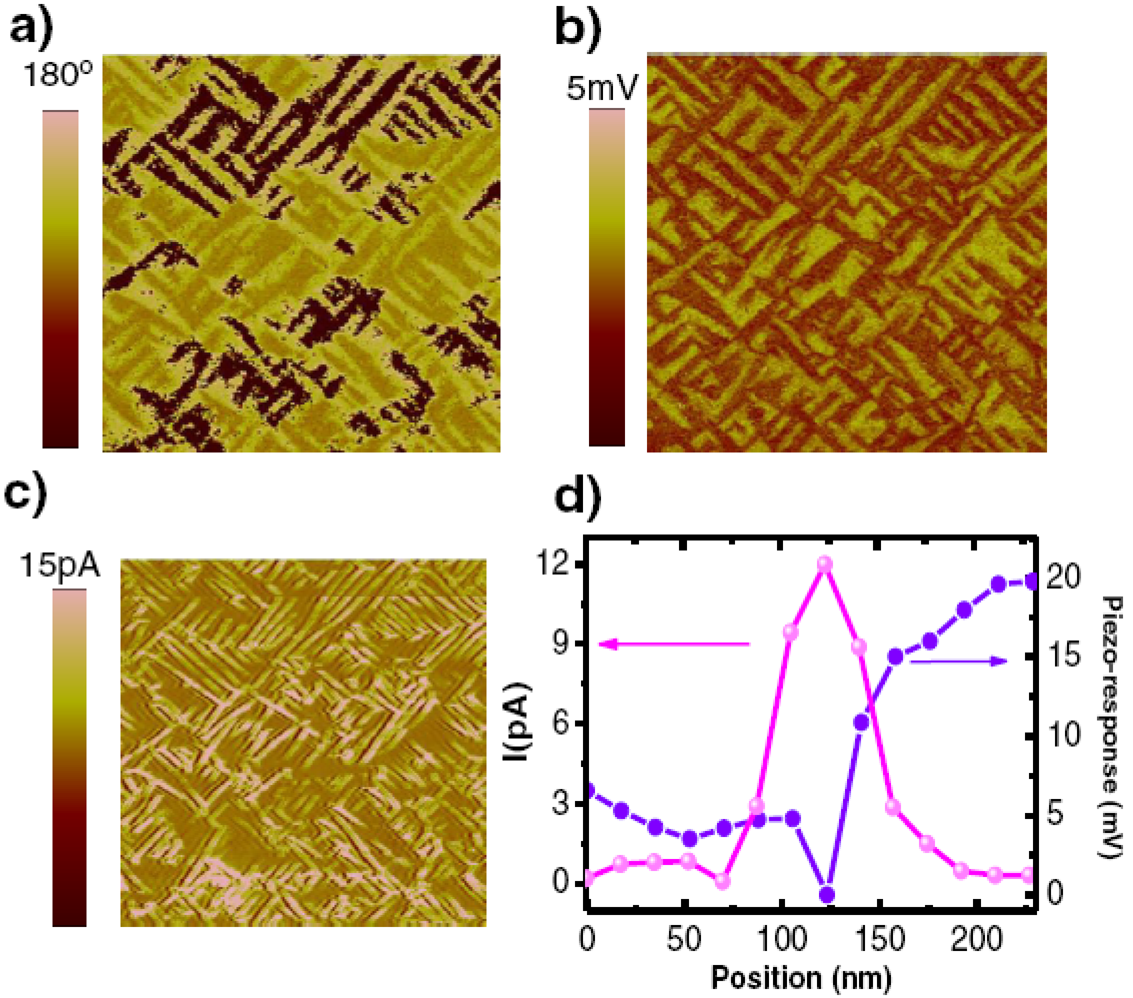
1. Multiferroics: $BiFeO_3$ thin films



- **Enhanced electrical conduction at domain walls- what is happening?**
- **How are structural and magnetic domains related in thin film multiferroics?**
- **LARMOR might allow domains and domain walls to be better studied.**

S. Farokhipoor and B. Noheda, *Phys. Rev. Lett.* **107**, 127601 (2011)

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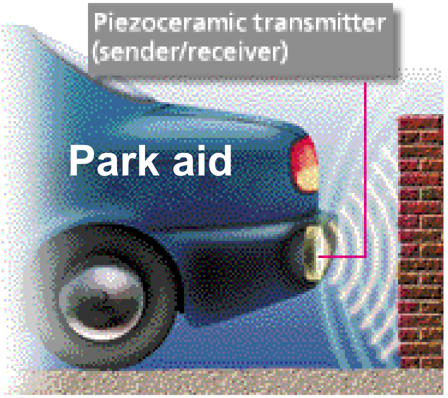
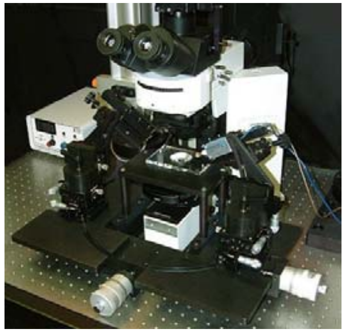
2. Piezoelectrics: $Pb_{1-x}Zr_xTiO_3$

Lighters, igniters

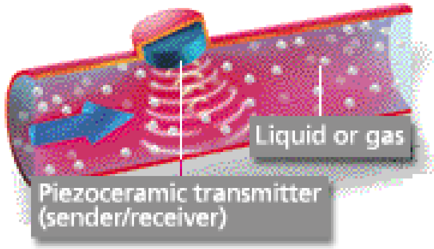
Blood pressure sensors

Inkjet printer heads





Micropositioners
+ manipulators



Flow measurement

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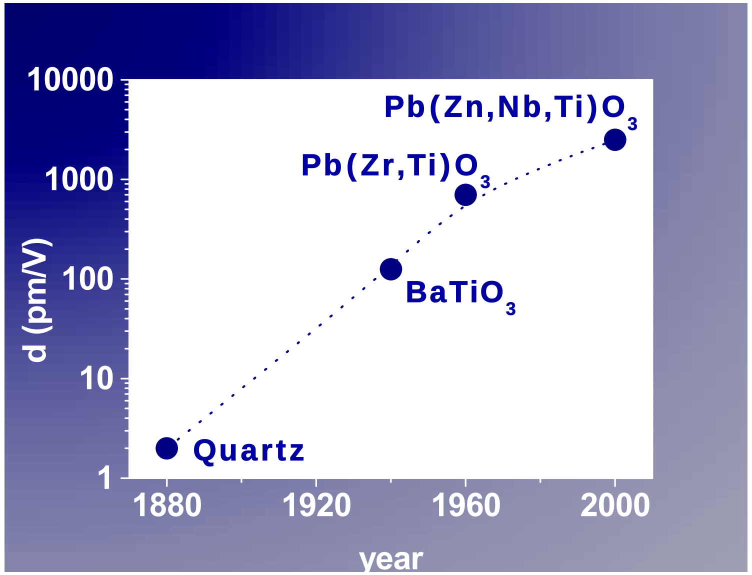
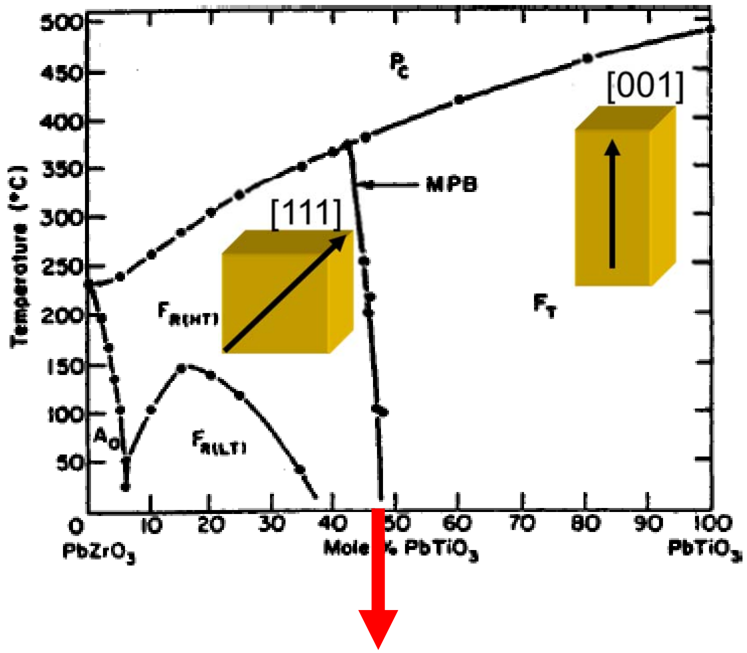
2. Piezoelectrics: $Pb_{1-x}Zr_xTiO_3$

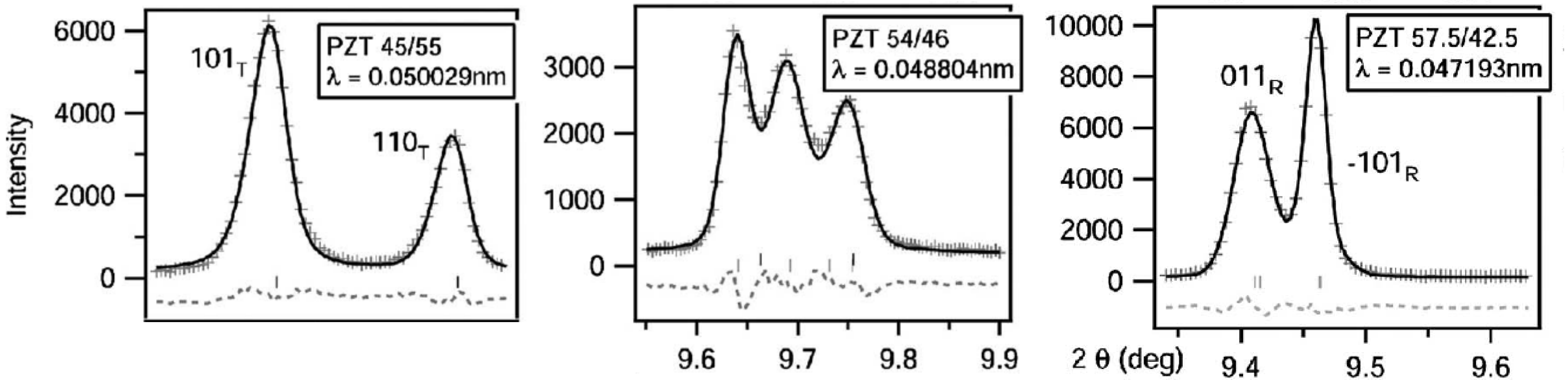


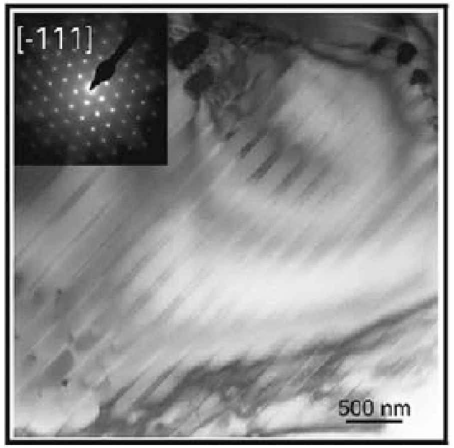


Morphotropic phase boundary between rhombohedral and tetragonal phases - monoclinic region?

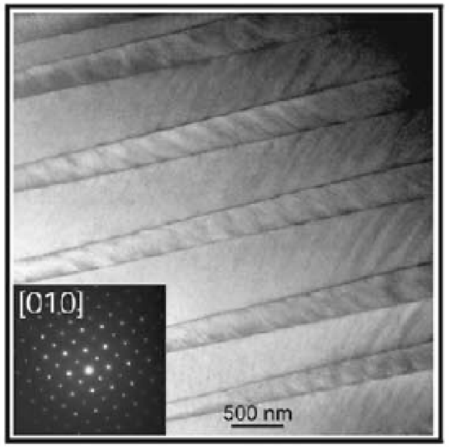
2. Piezoelectrics: $Pb_{1-x}Zr_xTiO_3$

Morphotropic phase boundary of PZT studied by synchrotron X-ray diffraction and TEM

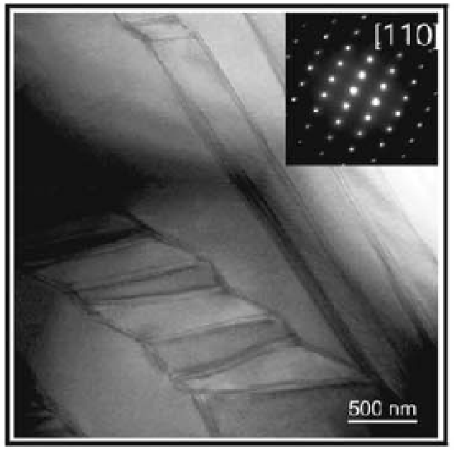




Tetragonal (T)



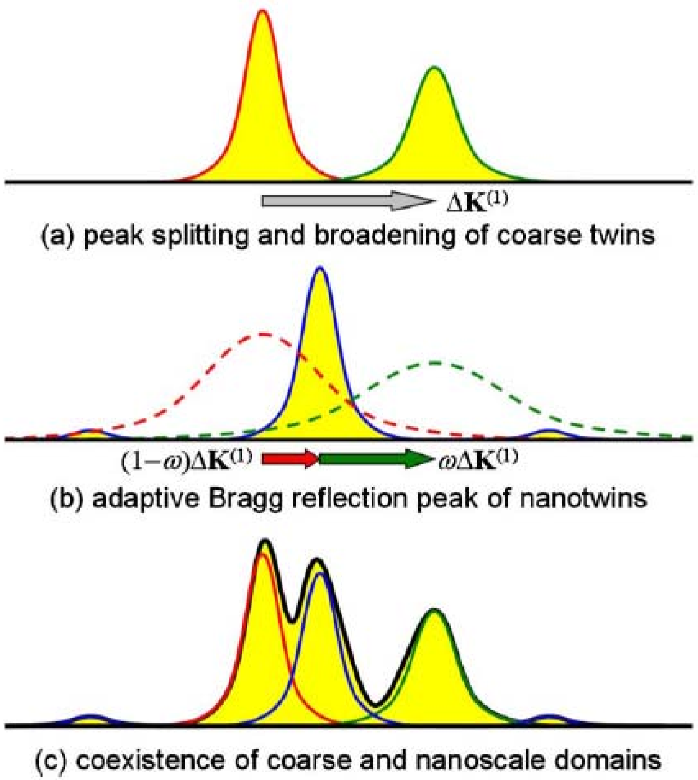
Monoclinic, or T+R?



Rhombohedral (R)

K. Schoenau et al., *Phys. Rev. B* **75**, 184117 (2007)

2. Piezoelectrics: $Pb_{1-x}Zr_xTiO_3$



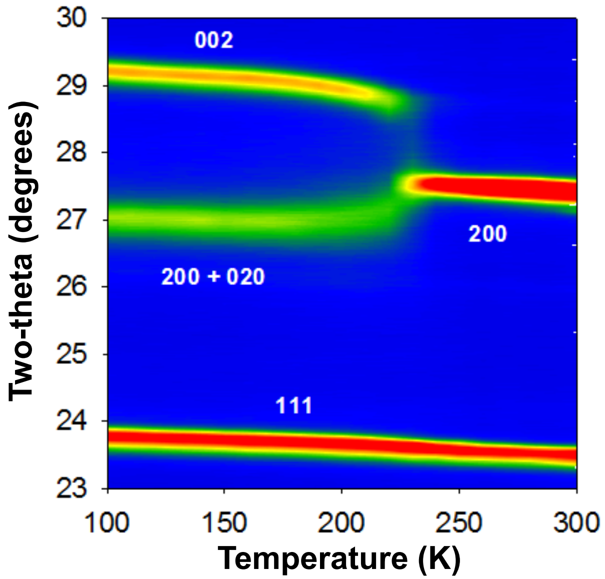
Nanotwins and nanodomains can give complex interference effects in "standard" diffraction

Yu.U. Wang, *Phys. Rev. B* **76**, 024108 (2007)

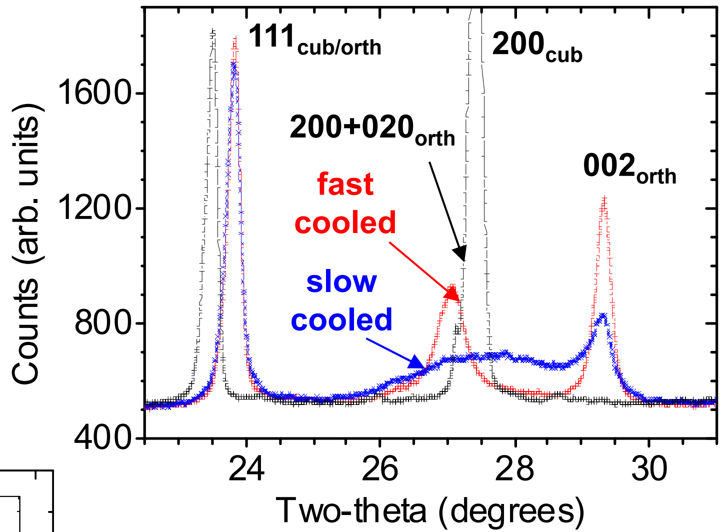
Problem resolved by Larmor diffraction?

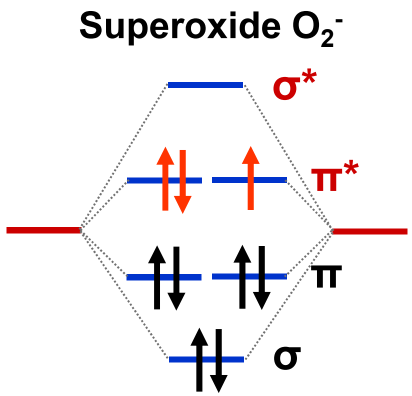
- **Do rhombohedral and tetragonal phases coexist? Size and shape of domains?**
- **Does the type and density of domains (domain walls) influence the piezoelectric coefficient?**

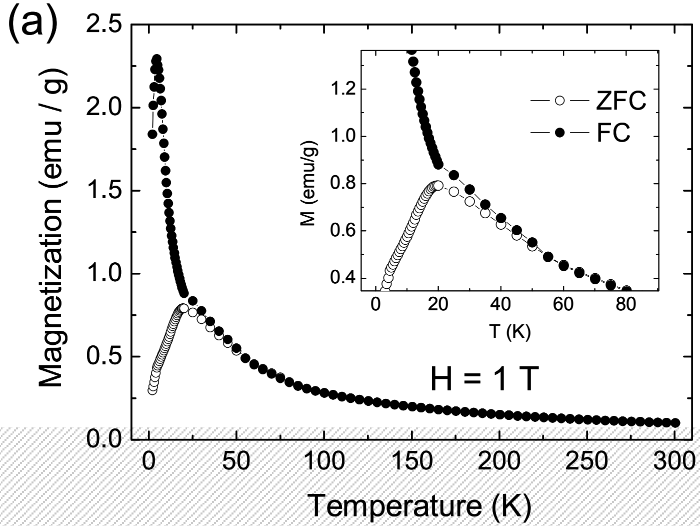
3. Magnetic alkali superoxides



$RbO_{1.72}$





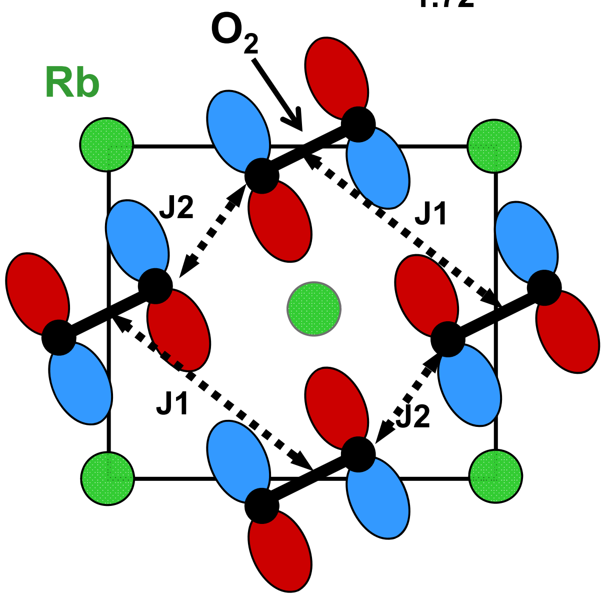


- **Slow cooled XRD pattern suggests long, thin nanodomains**
- **Different types of orbital ordering?**
- **Different magnetic ordering?**

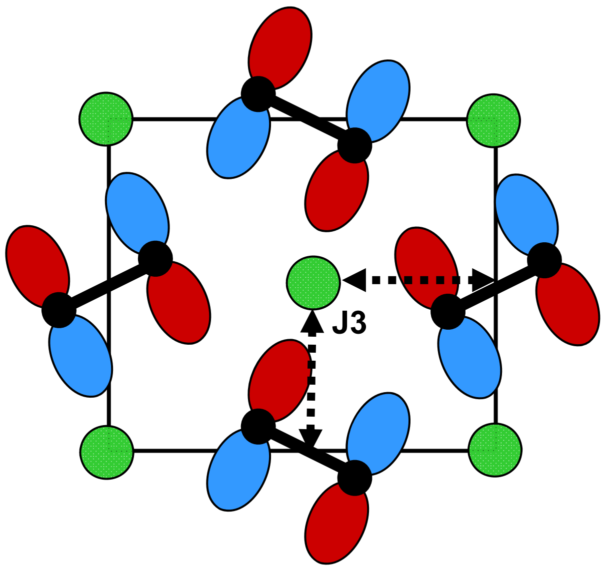
S. Riyadi et al., *Chem. Mater.* **23**, 1578 (2011)

3. Magnetic alkali superoxides

$RbO_{1.72}$: orbitally ordered domains?



Antiferromagnetic direct exchange



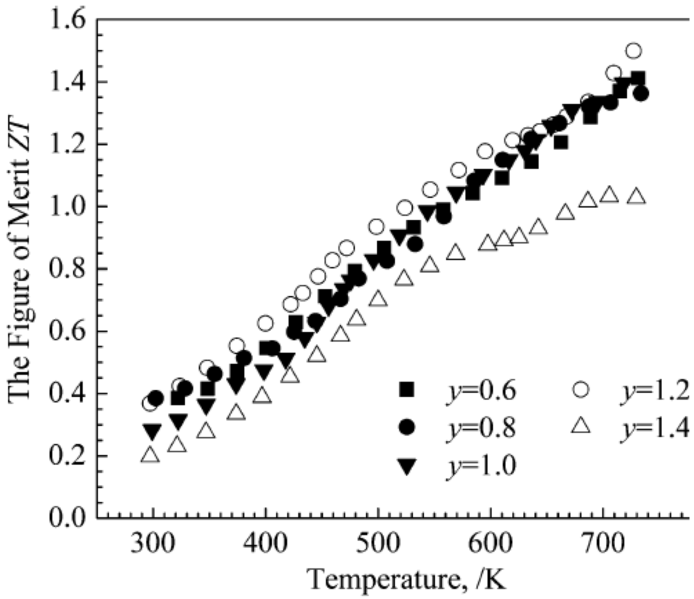
Ferromagnetic superexchange via Rb

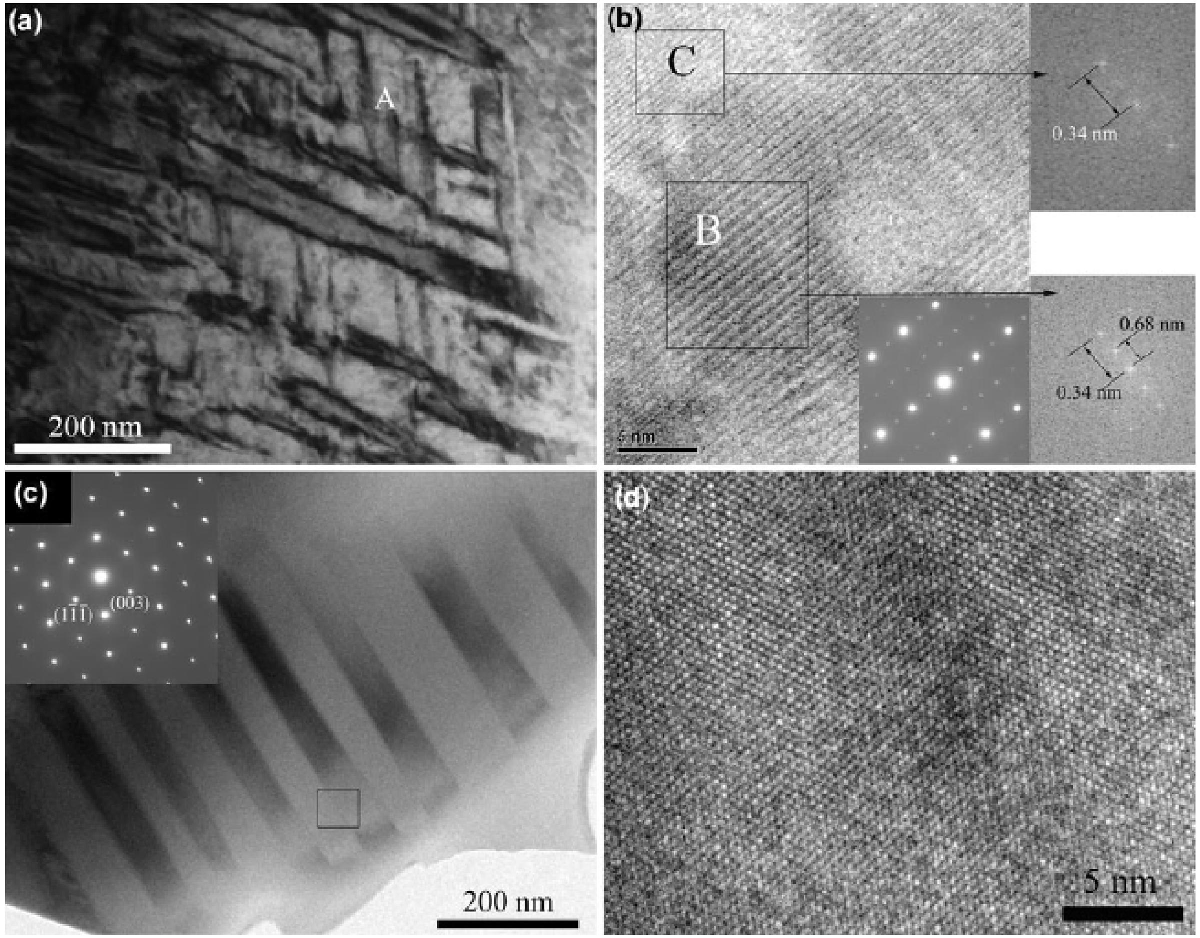
Larmor diffraction

- **Look for evidence of domains with different lattice parameters: could be different orbital orderings, Jahn-Teller distorted / non-distorted domains, or spinoidal decomposition.**
- **Cannot grow single crystals – but LARMOR should allow study of powder samples.**

4. Thermoelectric materials

$$zT = \frac{\alpha^2 T}{\rho \kappa}$$



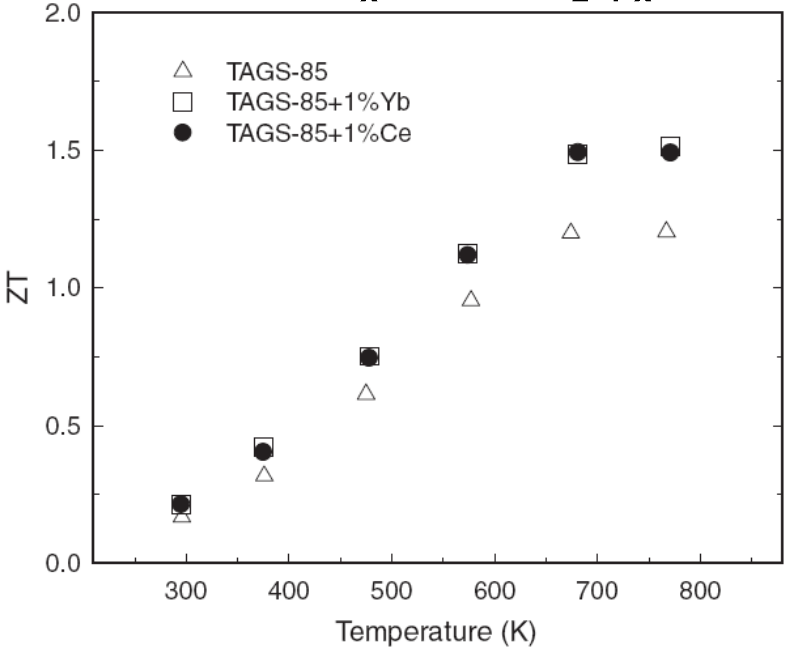


$(GeTe)_x(AgSbTe_2)_{1-x}$ S.H. Yang et al., *J. Electron. Mater.* **39**, 2127 (2010)

- **Complex antiphase domains and twin domains, also regions with doubled lattice spacing. This self-assembled nanostructuring is poorly understood.**

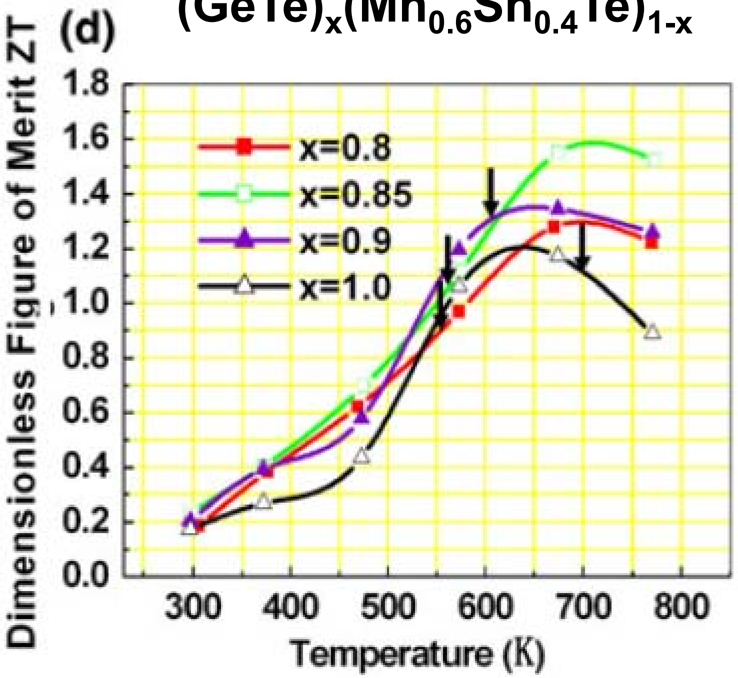
4. Thermoelectric materials

$(GeTe)_x(AgSbTe_2)_{1-x}$



E.M. Levin et al., *Adv. Func. Mater.* **21**, 441 (2011)

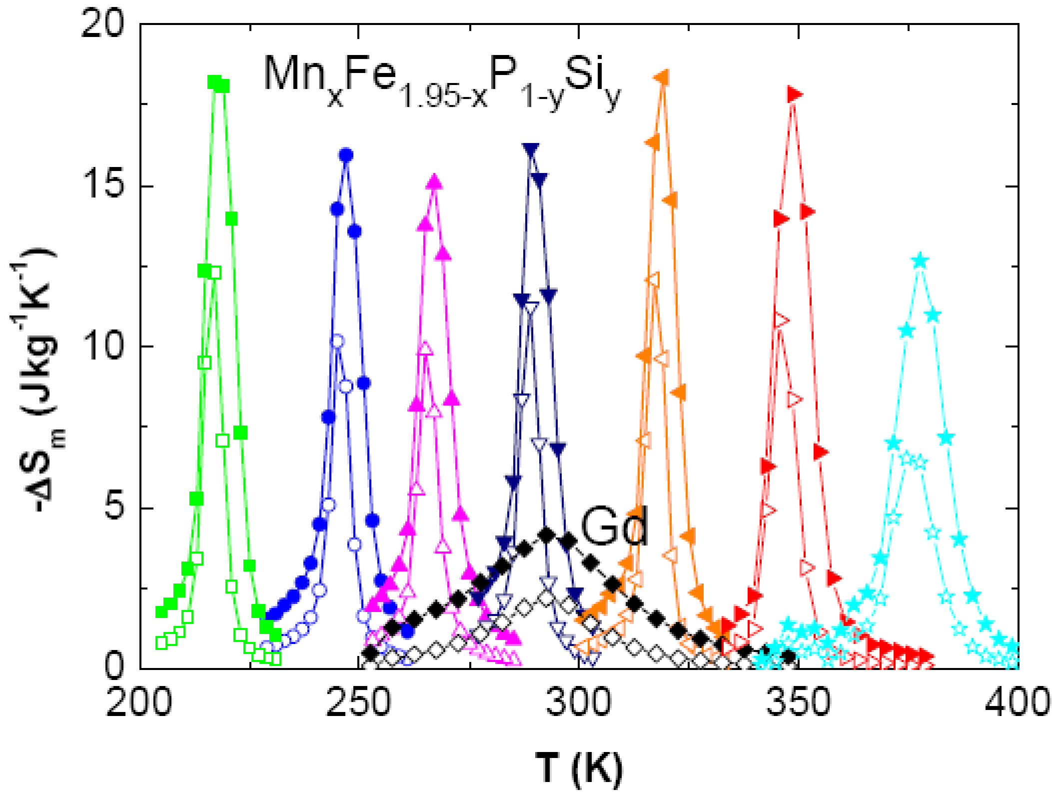
$(GeTe)_x(Mn_{0.6}Sn_{0.4}Te)_{1-x}$



L. Zhang et al., *J. Electron. Mater.* **40**, 1057 (2011)

- **Thermoelectric figure of merit enhanced by magnetic dopants.**
- **It appears that these dopants also affect the crystal structure, even at low concentrations. Is the microstructure / nanostructure changed?**

5. Giant magnetocaloric materials



N.H. Dung et al., *Adv. Energy. Mater.* **1**, 1215 (2011)

- **Study of first-order magnetic phase transitions**
- **Study of magnetic domain structures and their evolution with temperature and doping**

What sample environment do we need?

- Low temperatures (cryostat + dilution refrigerator?)
- High temperatures (to 1000 C?)
- Pressure cells
- Ability to measure samples with magnetic moments – Cryopad setup?

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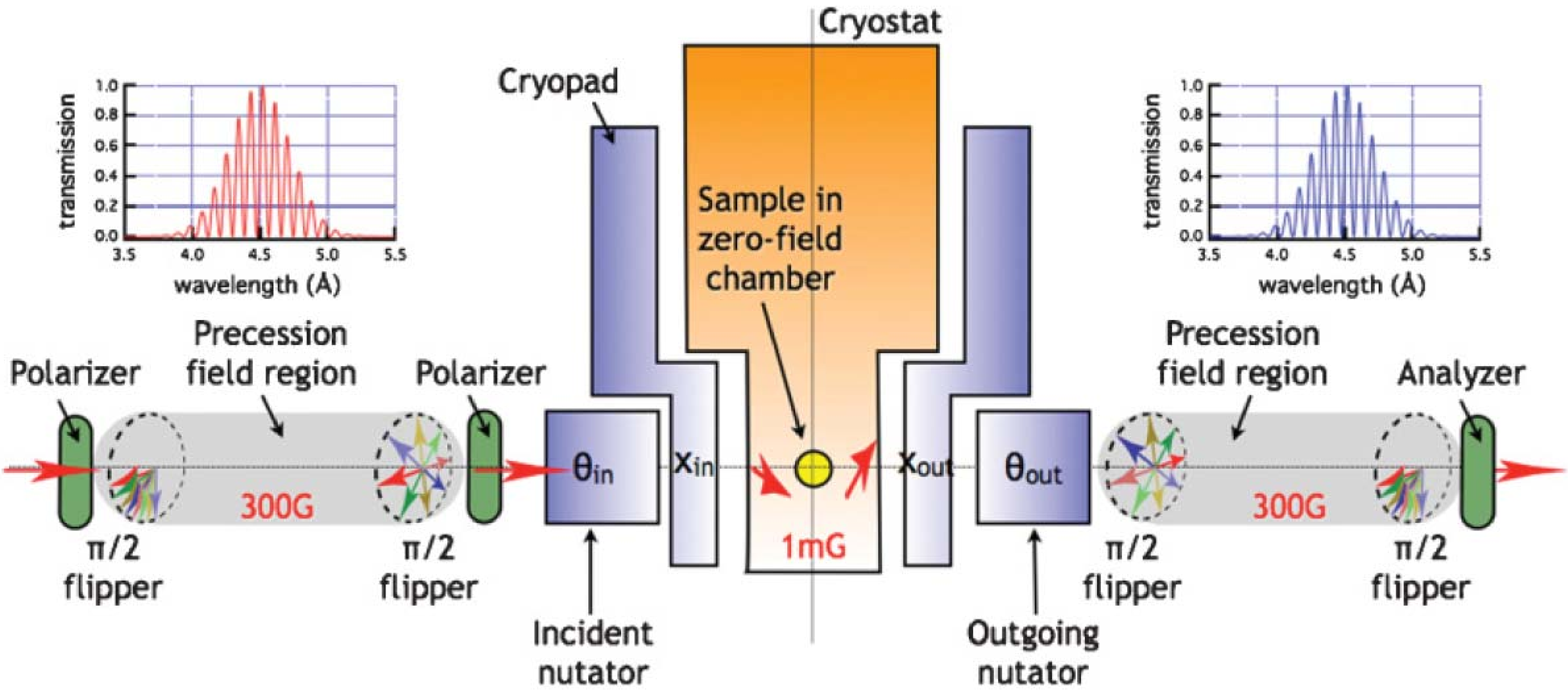
What sample environment do we need?

- Magnetic inhomgeneities (ferromagnets, chiral magnets, superconductors) will depolarize the beam in a complex way that is difficult to analyse.



C. Pappas et al., *Phys. Rev. B* **83**, 224405 (2011)