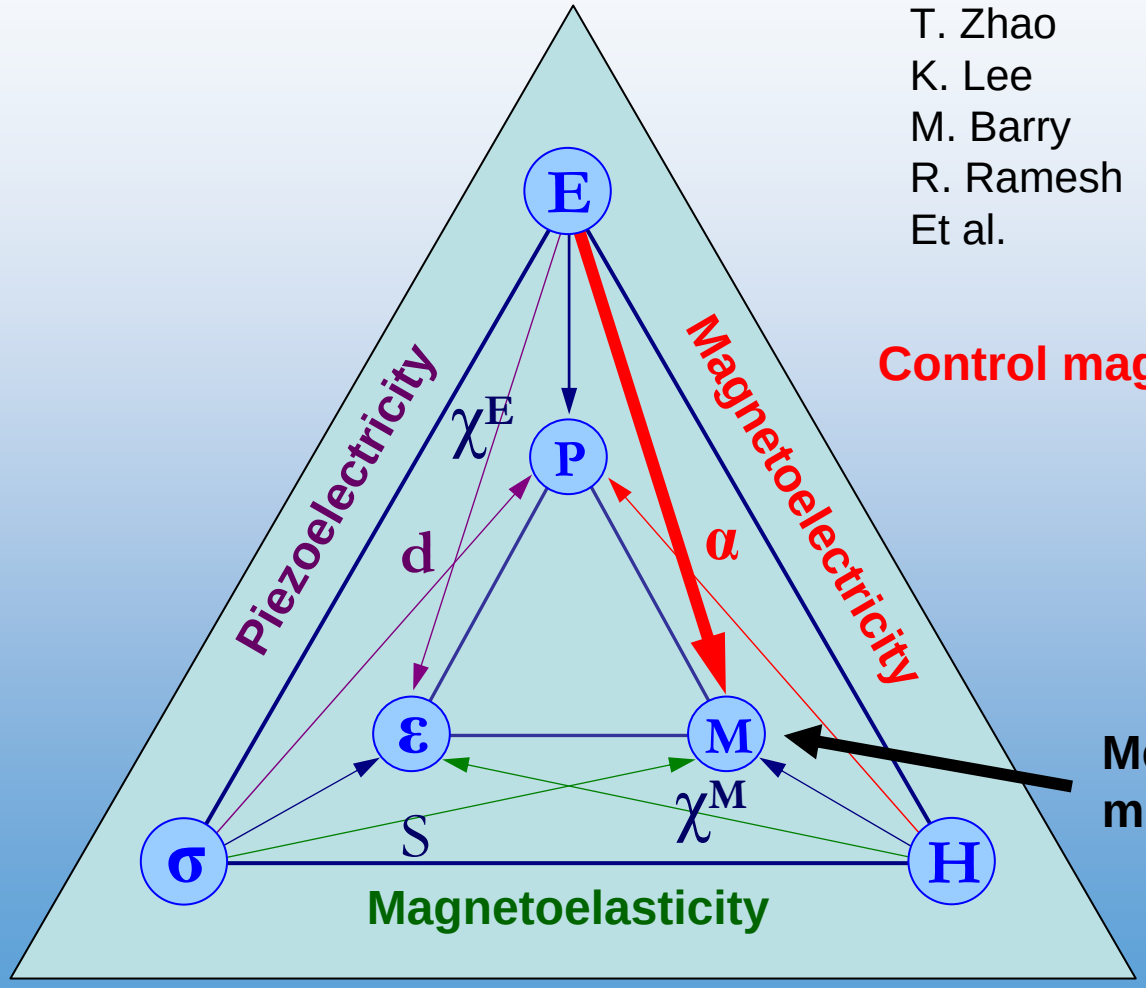
Electrical Control of Magnetism Using Multiferroic Materials



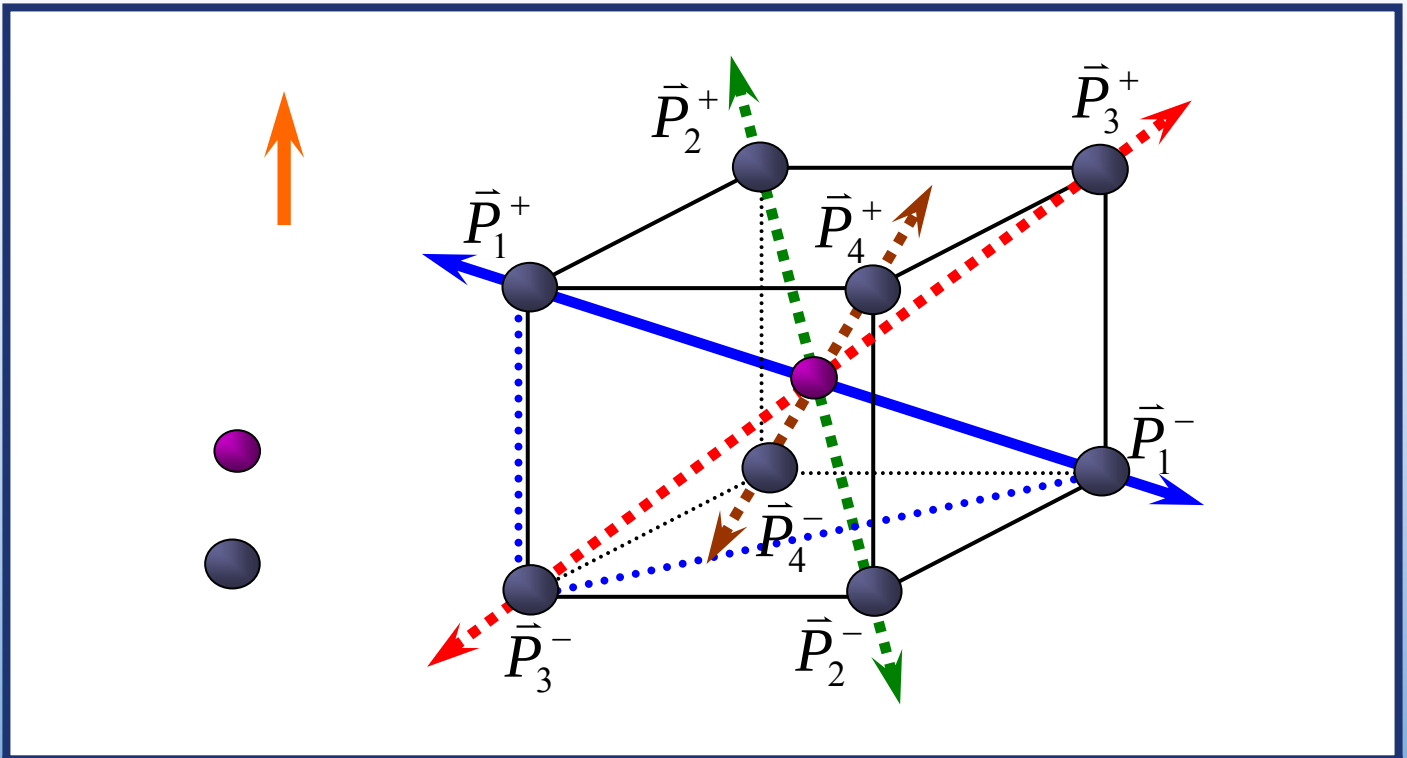
X-PEEM on Multiferroics, $BiFeO_3$

T. Zhao	Seagate
K. Lee	Berkeley
M. Barry	Berkeley
R. Ramesh	Berkeley
Et al.	

Control magnetism using electric fields

Measure the magnetization microscopically

$BiFeO_3(001)$

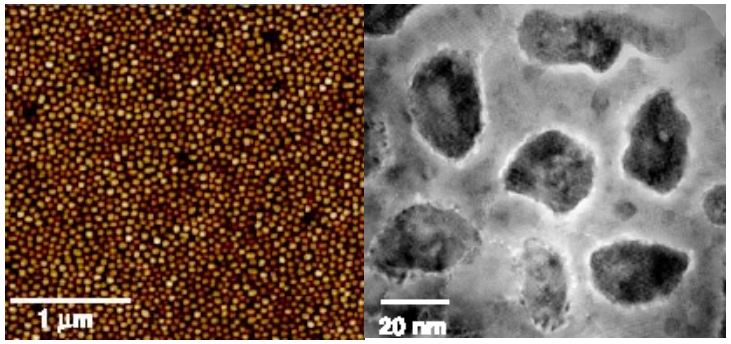


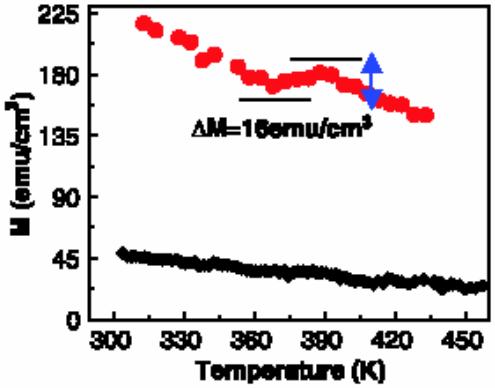
Polarization points in one of 8 possible {111} directions.

Ferromagnetic $CoFe_2O_4$ nano pillars in AFM-FE $BiFeO_3$ Matrix

Self organized epitaxial growth

AFM



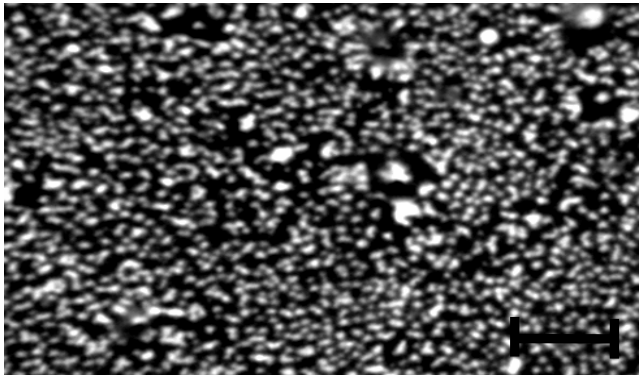


H. Zheng et al., Science 2004

Demonstrate coupling between FE matrix and FM pilars.

Co element contrast

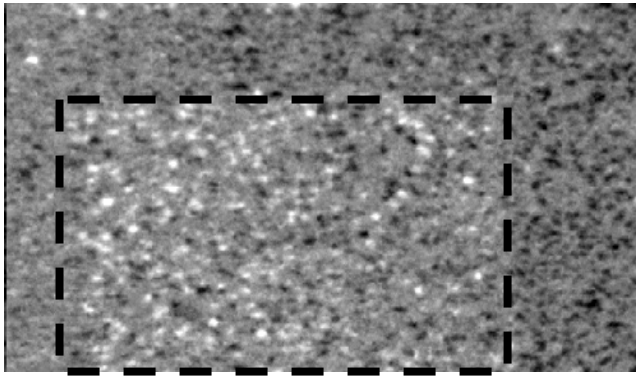
PEEM



2 µm

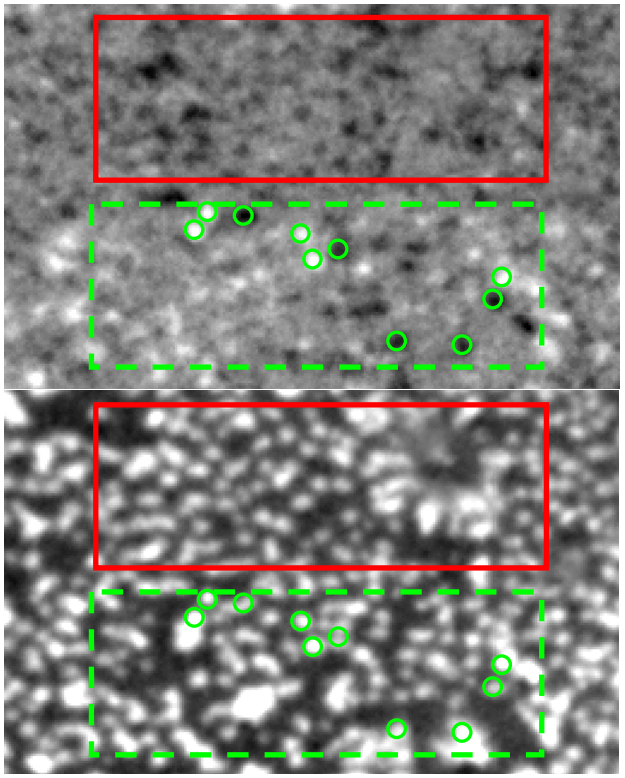
Co FM contrast (XMCD)

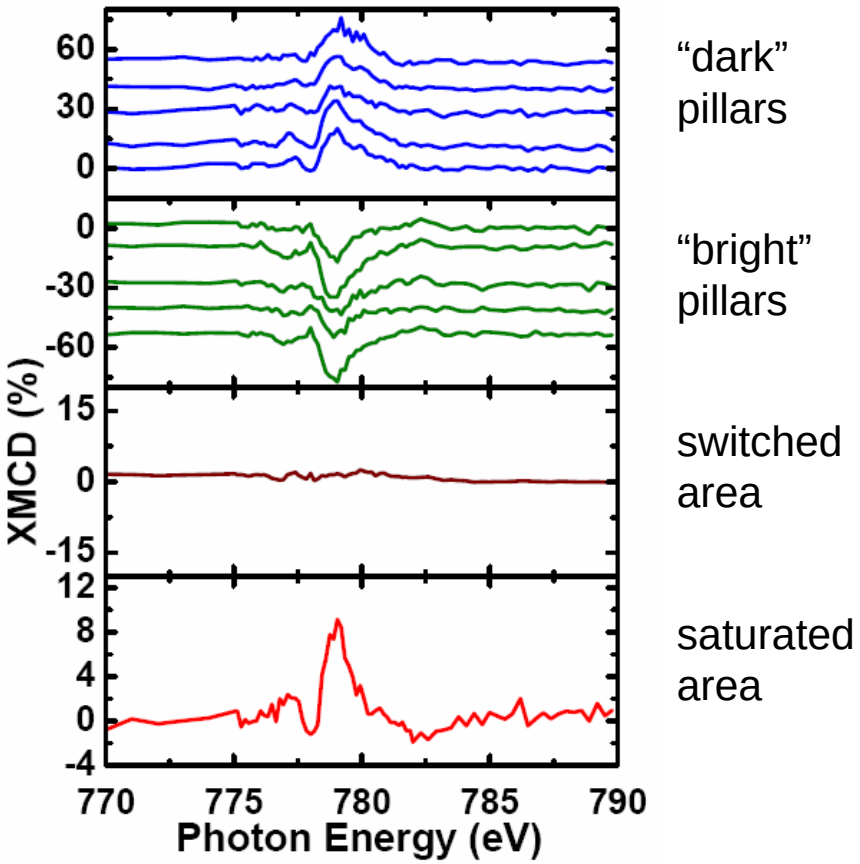
PFM poling



T. Zhao et al., Appl. Phys. Lett. 90, 123104 (2007)

Spectromicroscopy on $CoFe_2O_4$



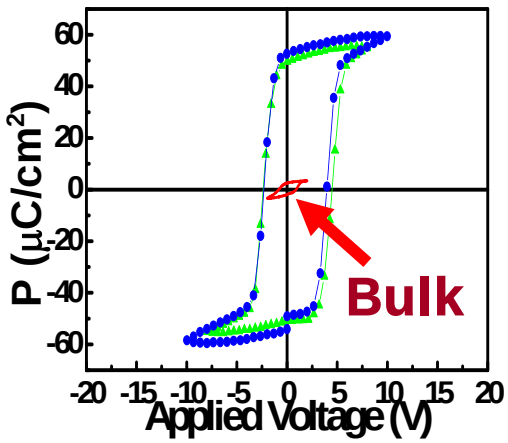


Poling of ferroelectric $BiFeO_3$ randomizes the magnetization in $CoFe_2O_4$ nano pillars

T. Zhao et al., Appl. Phys. Lett. 90, 123104 (2007)

Magnetic Structure of $BiFeO_3$ Films

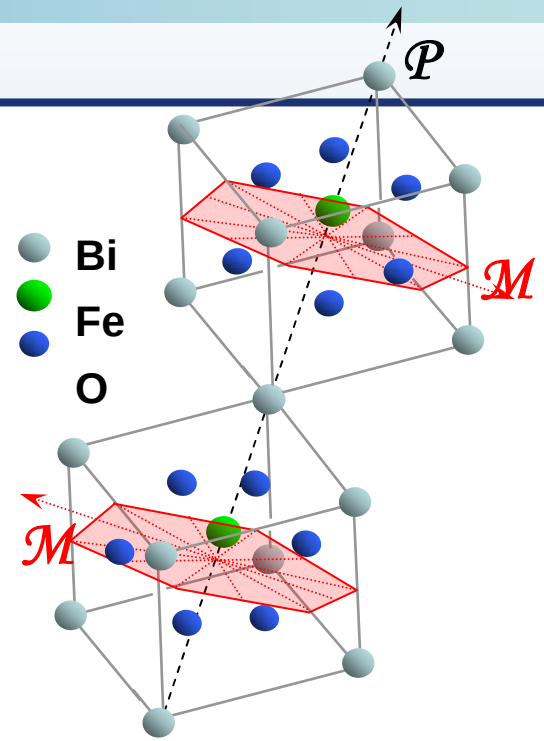
$BiFeO_3$ - Ferroelectric antiferromagnet



Ederer and Spaldin, PRB 71(2005)

T_C ~ 1103K

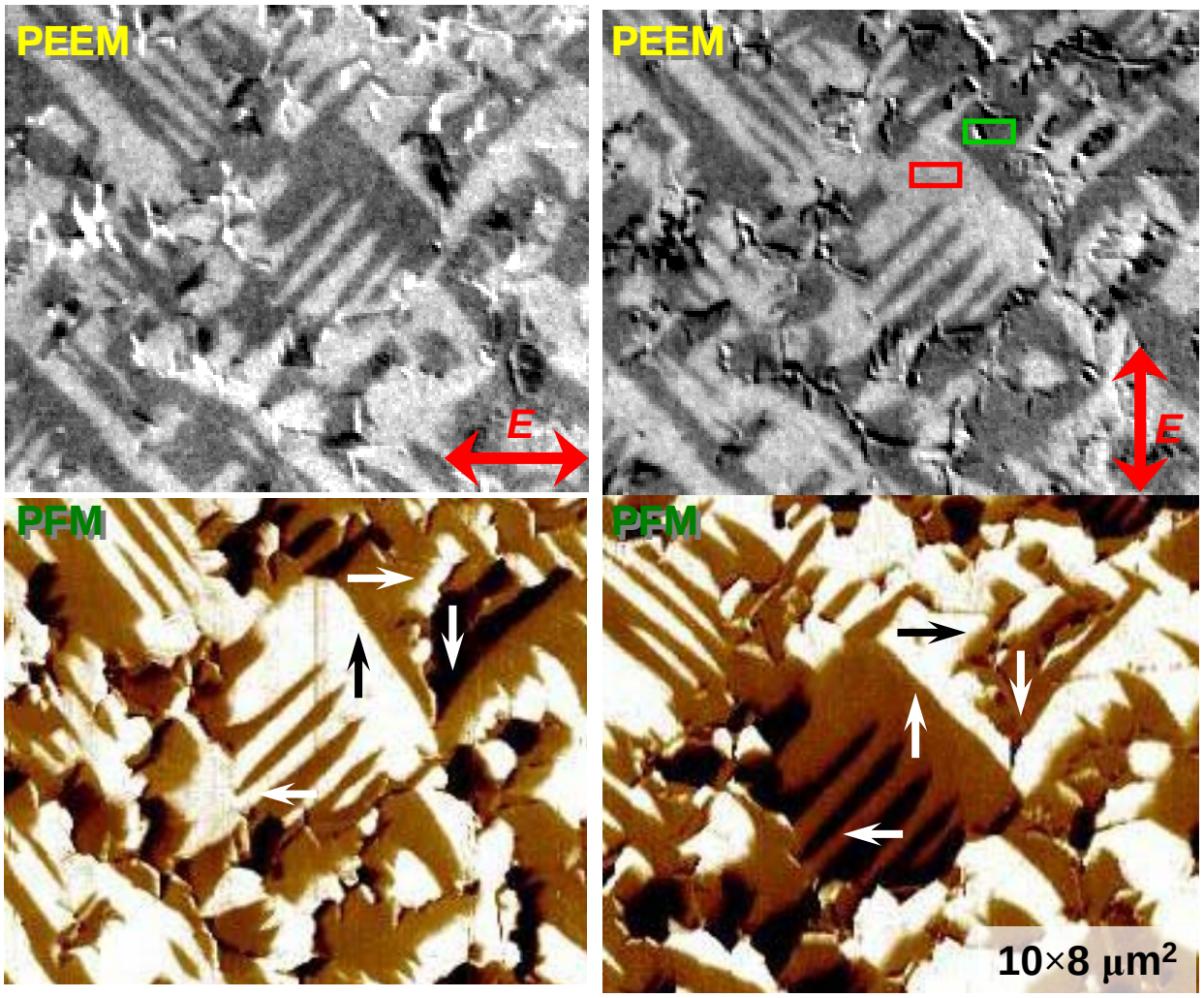
T_N ~ 643K



Magnetic plane is perpendicular to the polarization direction.

This sample: 600 nm $BiFeO_3$ / $SrRuO_3$/ $SrTiO_3$

Domain Structure of $BiFeO_3$



x-ray linear dichroism at Fe L_2 edge

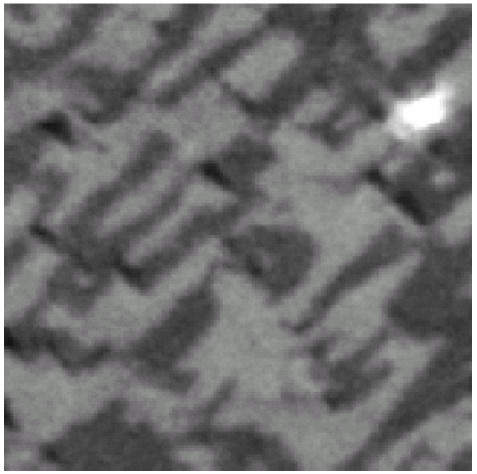
- contrast reversal proves dichroic origin
- images match PFM images of FE structure
- magnetic or charge dichroism?

T. Zhao et al., Nature Materials 5, 823 (2006)

AFM structure follows FE structure after poling

PFM

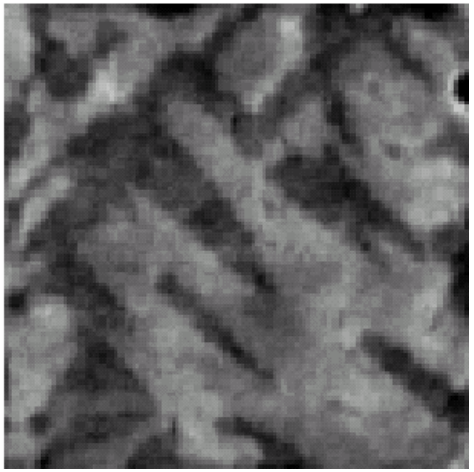
BEFORE SWITCHING



PEEM

PFM

AFTER SWITCHING

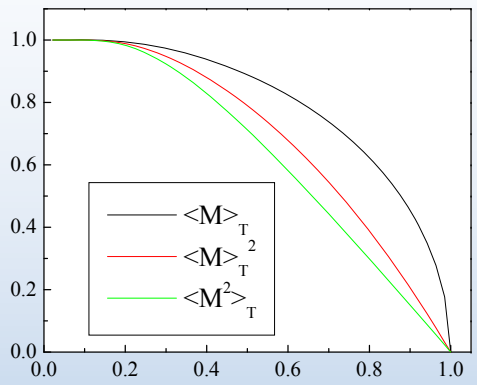


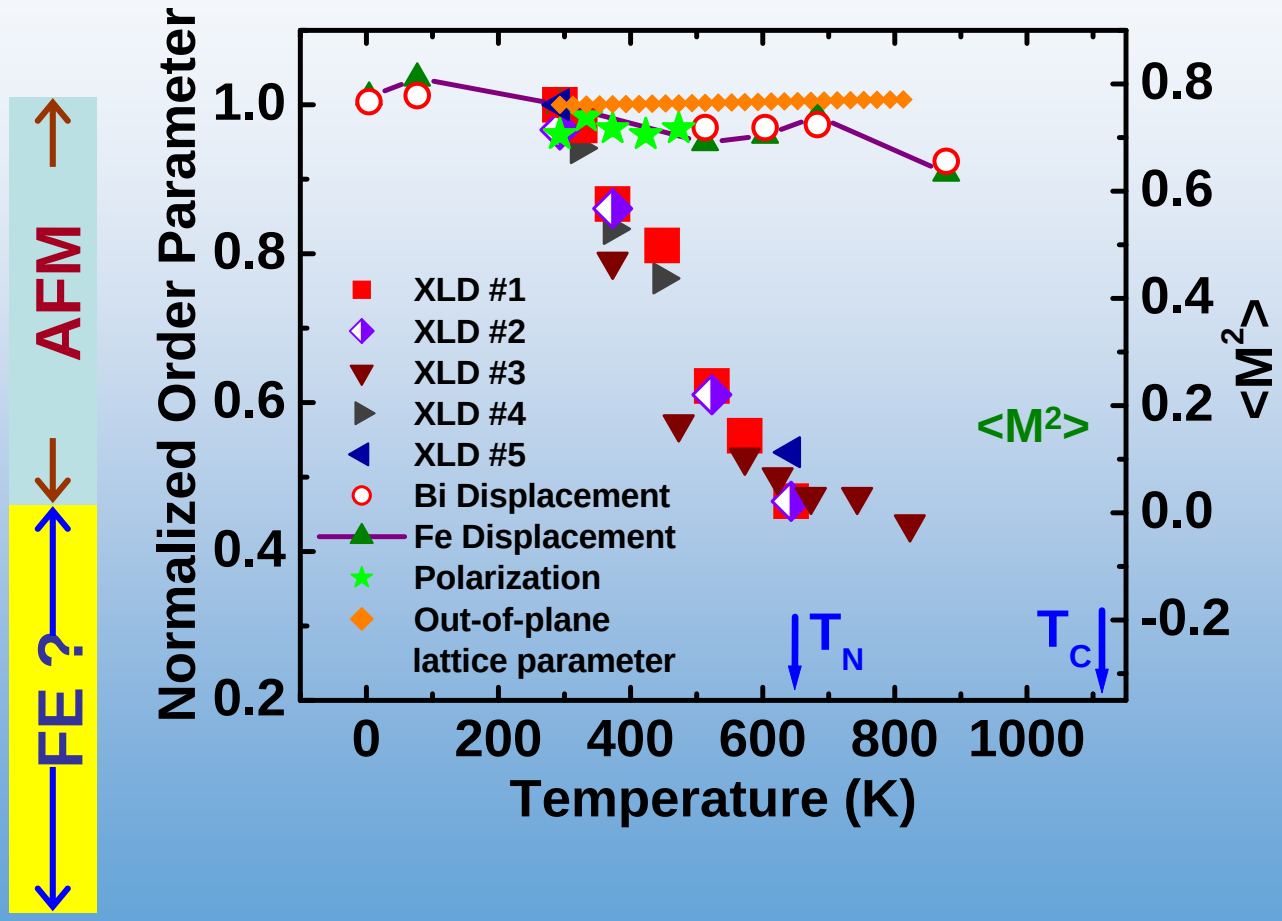
PEEM

Deconvolve? magnetic and ferroelectric contribution.

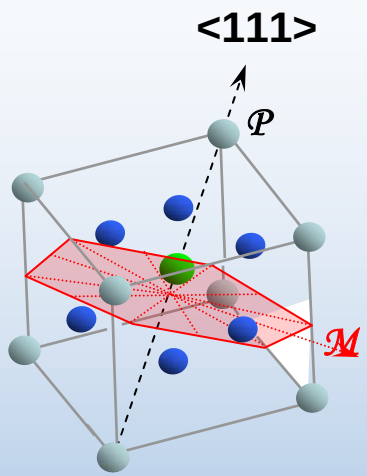
Magnetic axis?

Temperature Dependence Shows Contrast Dominated By Magnetism

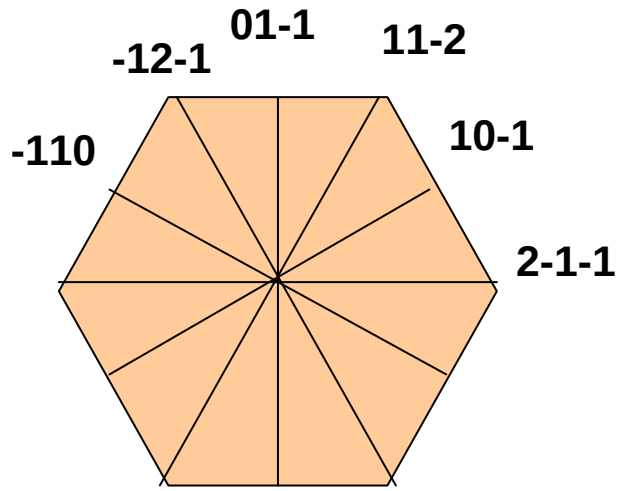




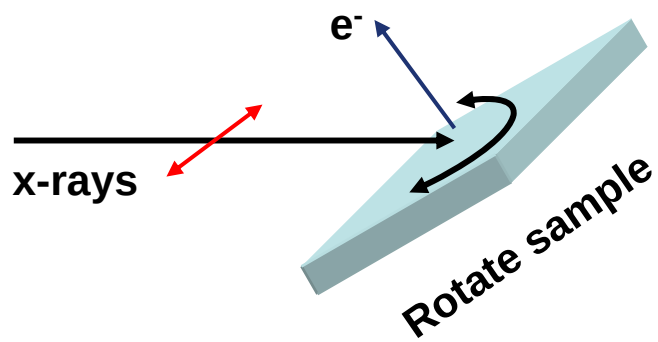
Determine Magnetic Structure of $BiFeO_3$



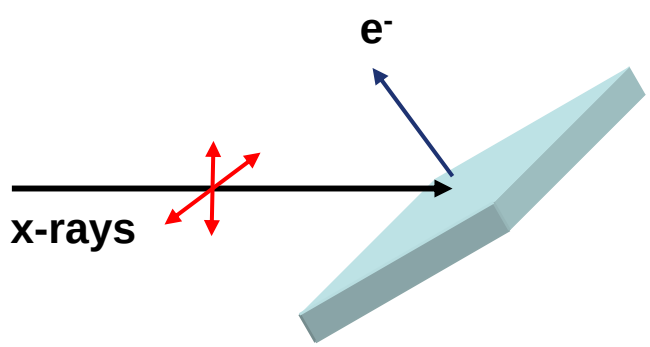
Six unique low index axes in (111) plane.



linearly polarized

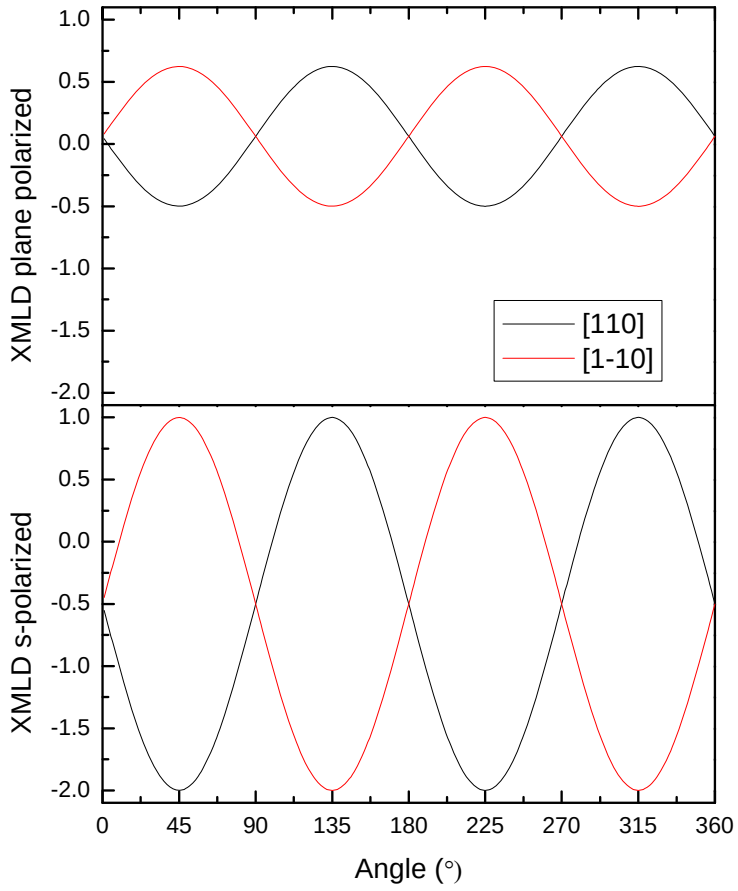


Circularly (plane) polarized

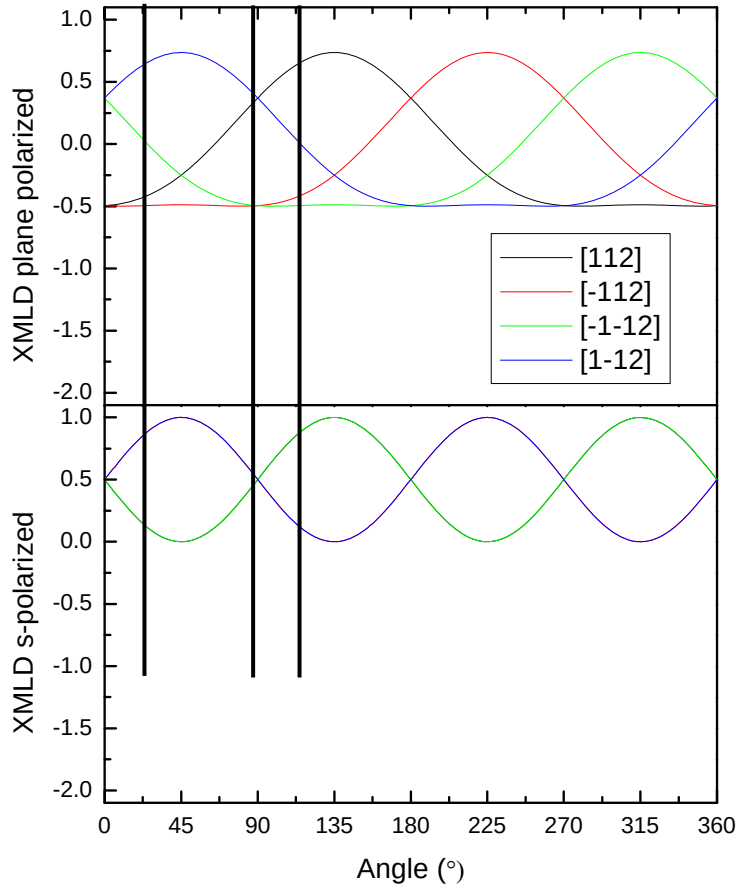


Angle Dependent Contrast

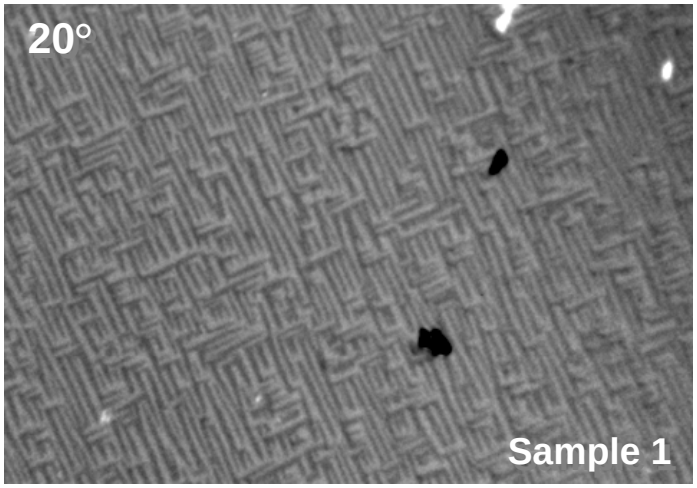
<110> (in-plane)



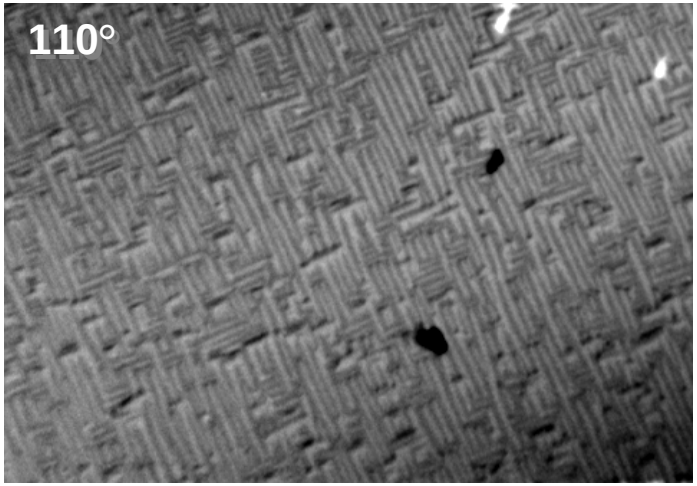
<112> (out-of-plane)

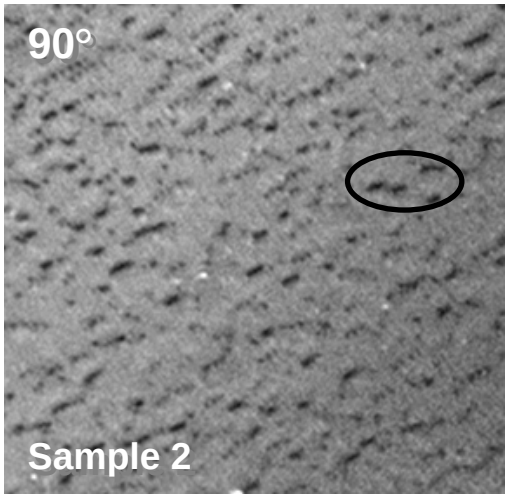


XMLD Using S-Polarized X-rays

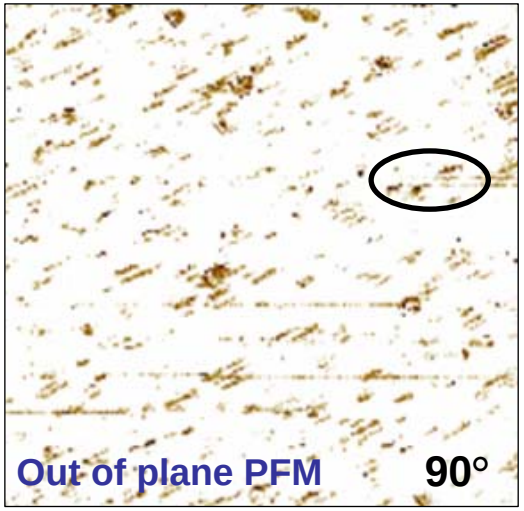


Two contrast levels which reverse upon 90° rotation

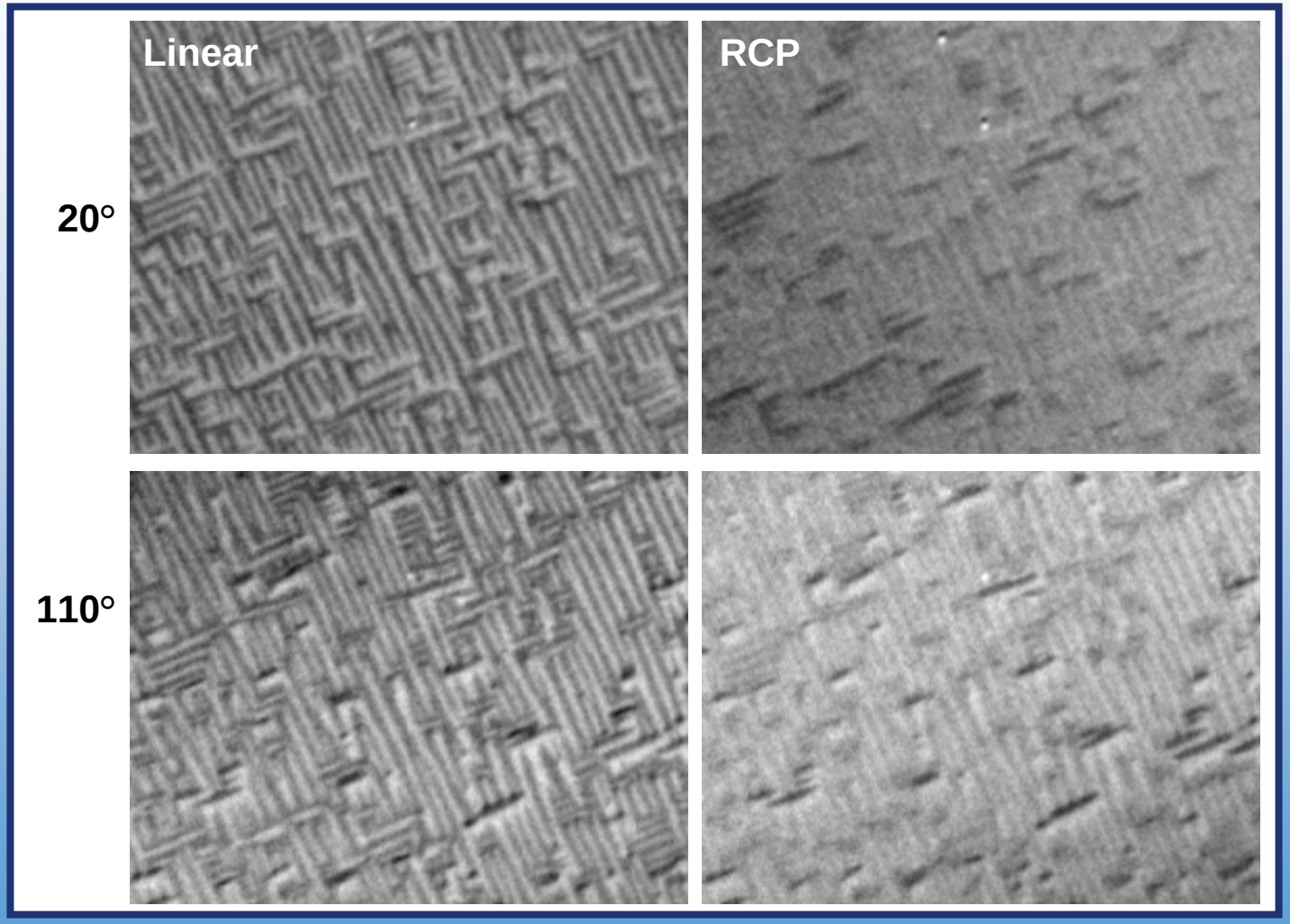




Low contrast at intermediate angle



Compare S-, Plane Polarization



Preliminary Conclusions

- X-ray Magnetic Dichroism (XMD) permits us to image ferro-and antiferromagnetic materials/oxides at high spatial resolution.
- $BiFeO_3$ antiferromagnetic domains couple to ferroelectric domains and can be switched.
- $BiFeO_3$ (001) and (110) have easy magnetic axes, while $BiFeO_3$ (111) may have easy plane.
- Additional complication: charge dichroism originating from ferroelectricity may be superimposed on magnetic dichroism => complex analysis.
- Axis may dependent on substrate, orientation, cap layer…

Acknowledgements

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