PAUL SCHERRER INSTITUT

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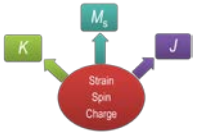
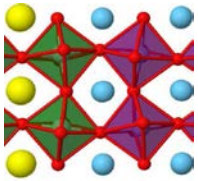
Paul Scherrer Institut
Carlos A. F. Vaz

Inducing interfacial couplings in multiferroic heterostructures

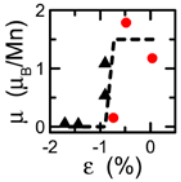
Outline



Interfacial phenomena in manganite heterostructures

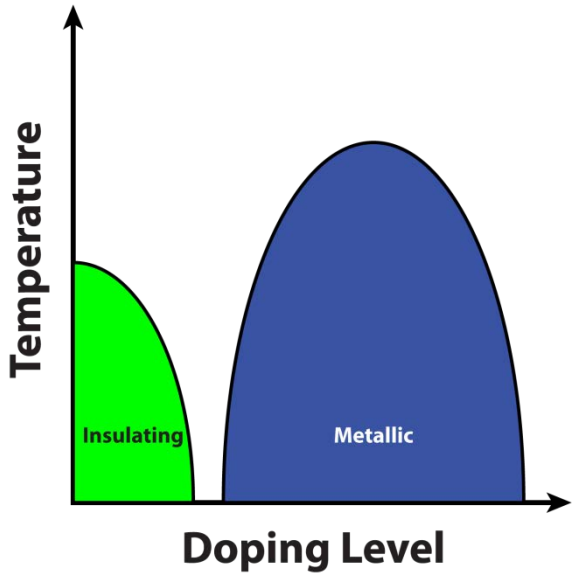


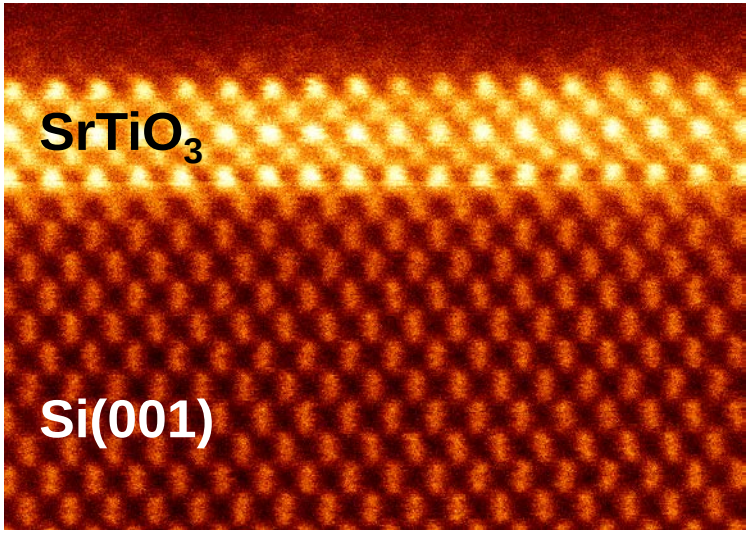
Interfacial resonant phonon-coupling in LSMO/$SrTiO_3$



$La_{1-x}Sr_xMnO_3$ thin films at near half doping

Complex oxides



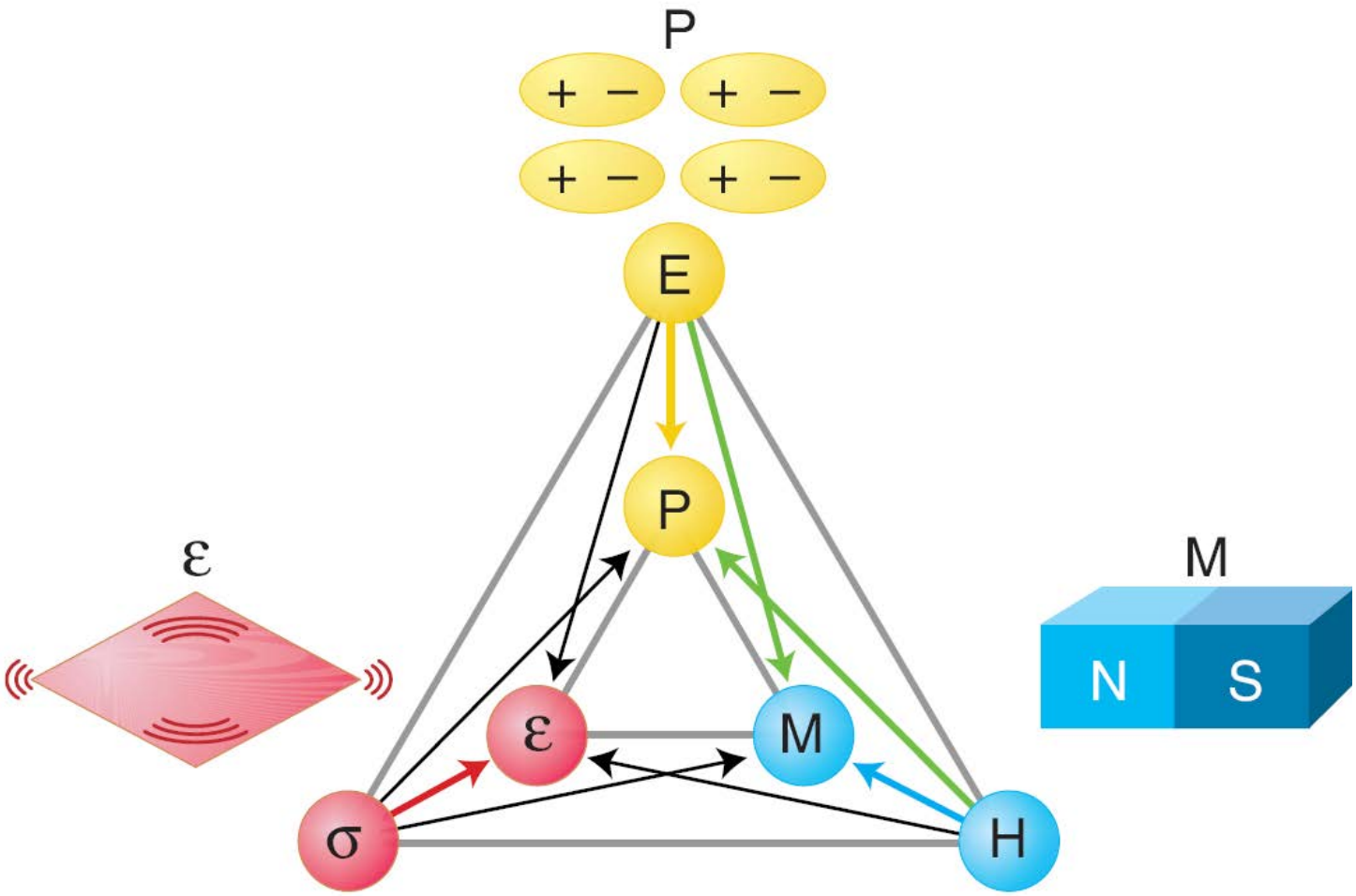


F. J. Walker, Yale

- multifunctionality (FM, FE, high-κ, M, IS, SC)
- high spin polarisation (LSMO, LCMO, Fe_3O_4, …)
- control of atomic structure (MBE, sputtering)
- compatibility (hybrid structures)
- onset on intrinsic interfacial effects in oxide heterostructures

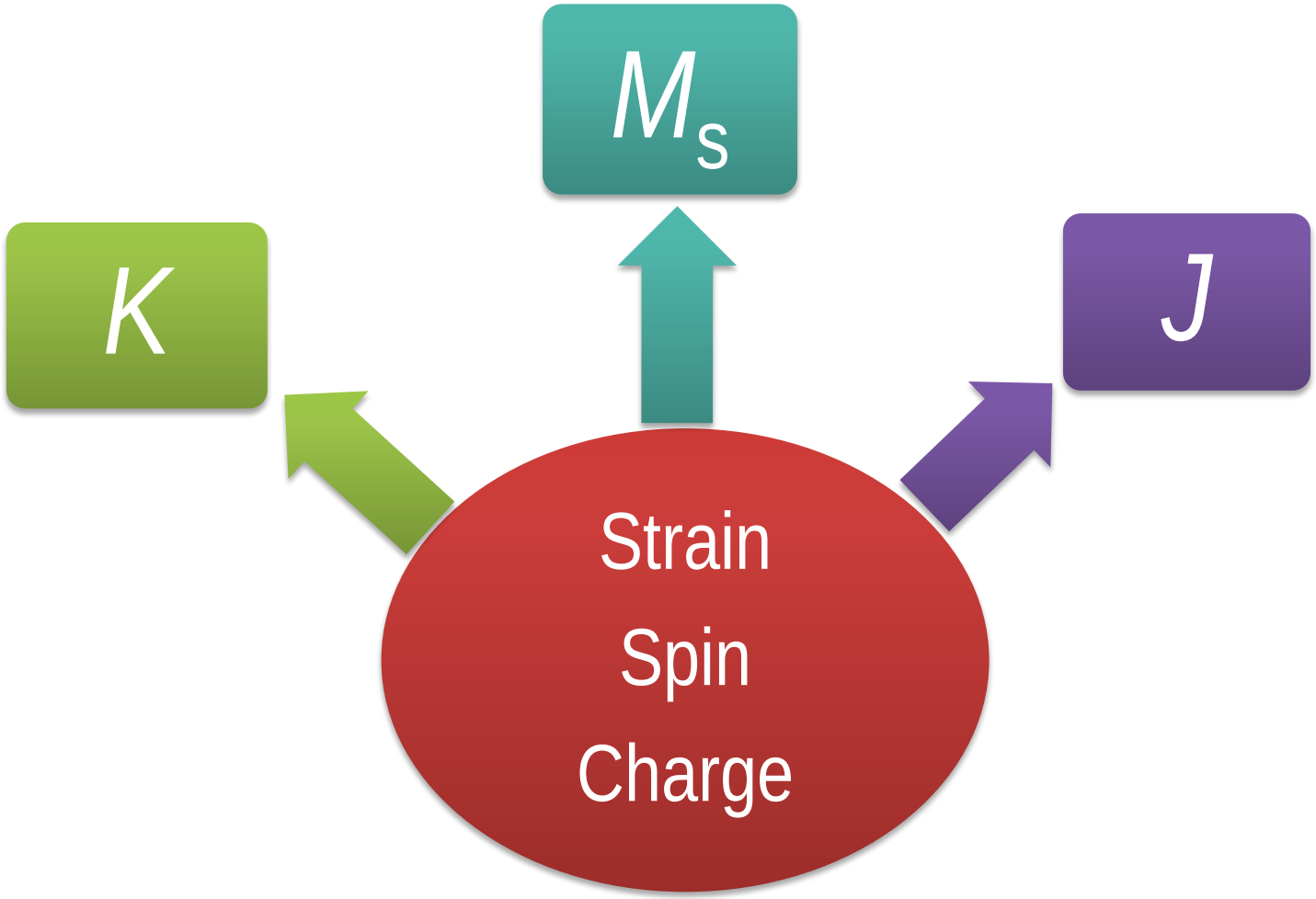
Vaz, Walker, Ahn, Ismail-Beigi, JPCM 27 (2015) 123001

Magnetoelectric coupling



Spaldin and Fiebig, Science 309 (2005) 391
Vaz, Hoffman, Ahn, Ramesh, Adv. Mater. 22 (2010) 2900

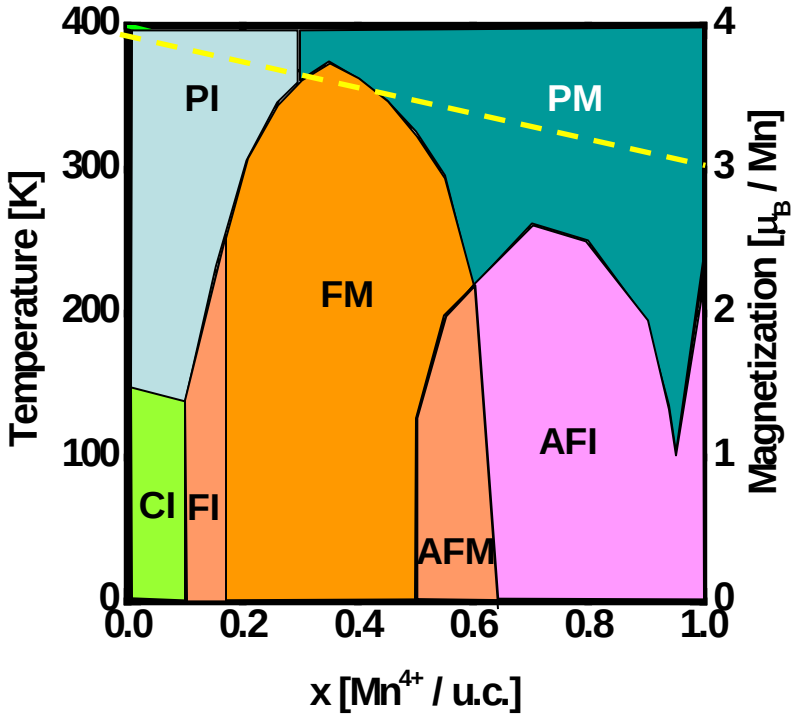
Electric field control of magnetism



Vaz, JPCM 24 (2012) 333201
Vaz, Staub, J. Mater. Chem. C 1 (2013) 6731

CMR manganites

$La_{1-x}Sr_xMnO_3$



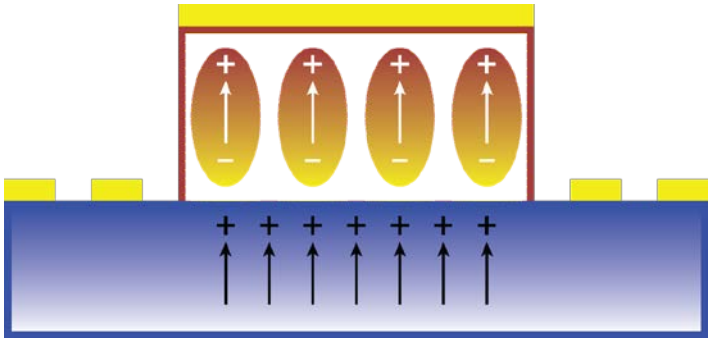
$La^{3+}Mn^{3+}O^{2-}_3$

S=2

$Sr^{2+}Mn^{4+}O^{2-}_3$

S=3/2

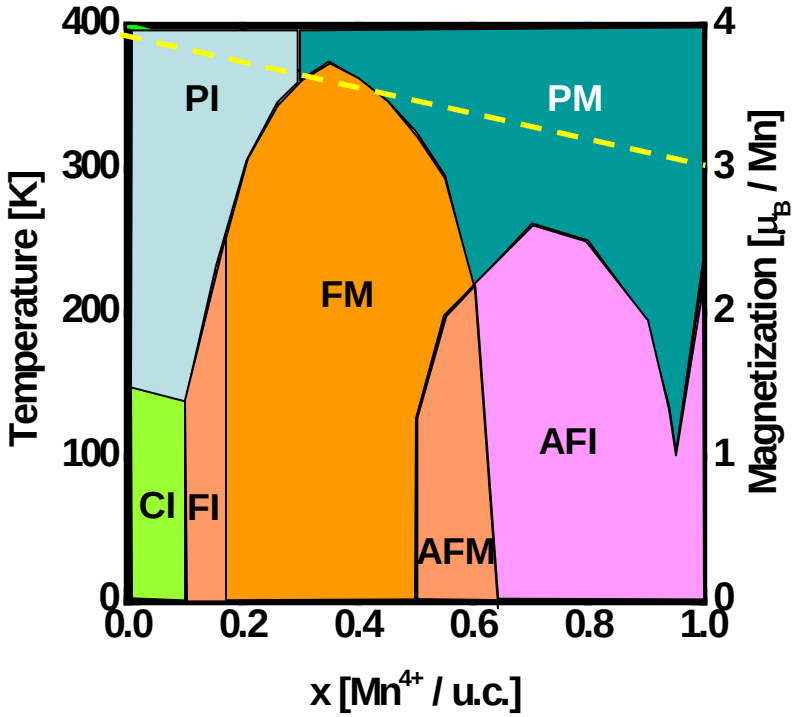
Ferroelectric field effect



accumulation state

CMR manganites

$La_{1-x}Sr_xMnO_3$



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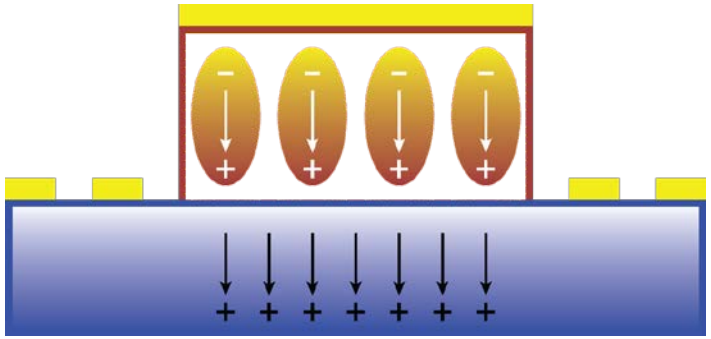
Ferroelectric field effect

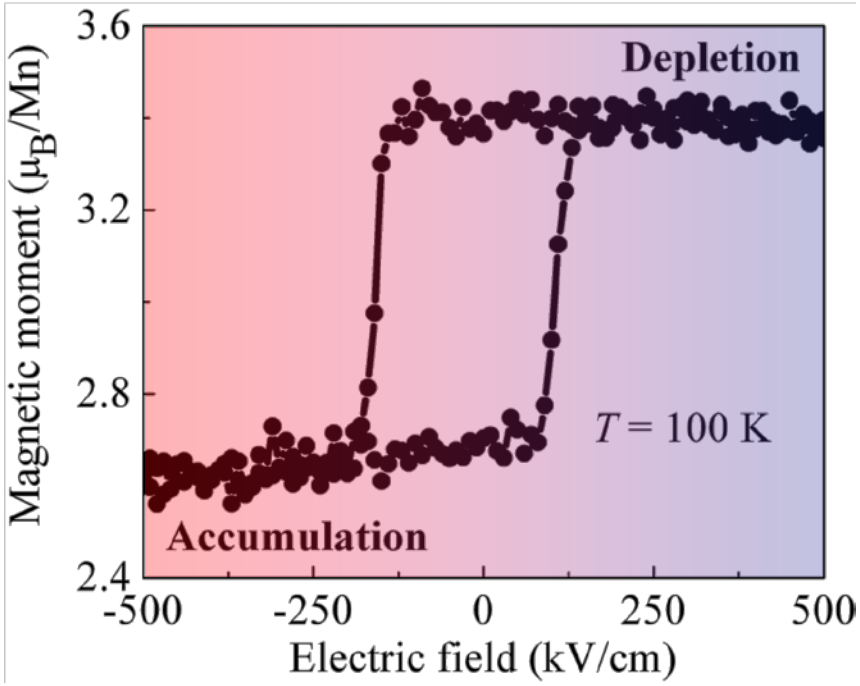


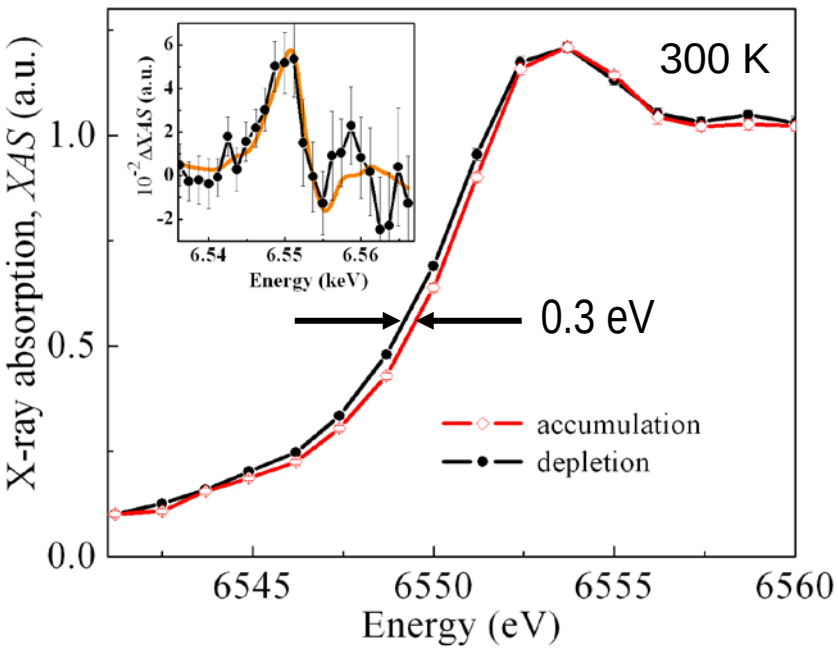
depletion state

- Reversible
- Non-volatile

Magnetoelectric coupling in PZT/LSMO

12 u.c. $La_{0.8}Sr_{0.2}MnO_3$/PZT



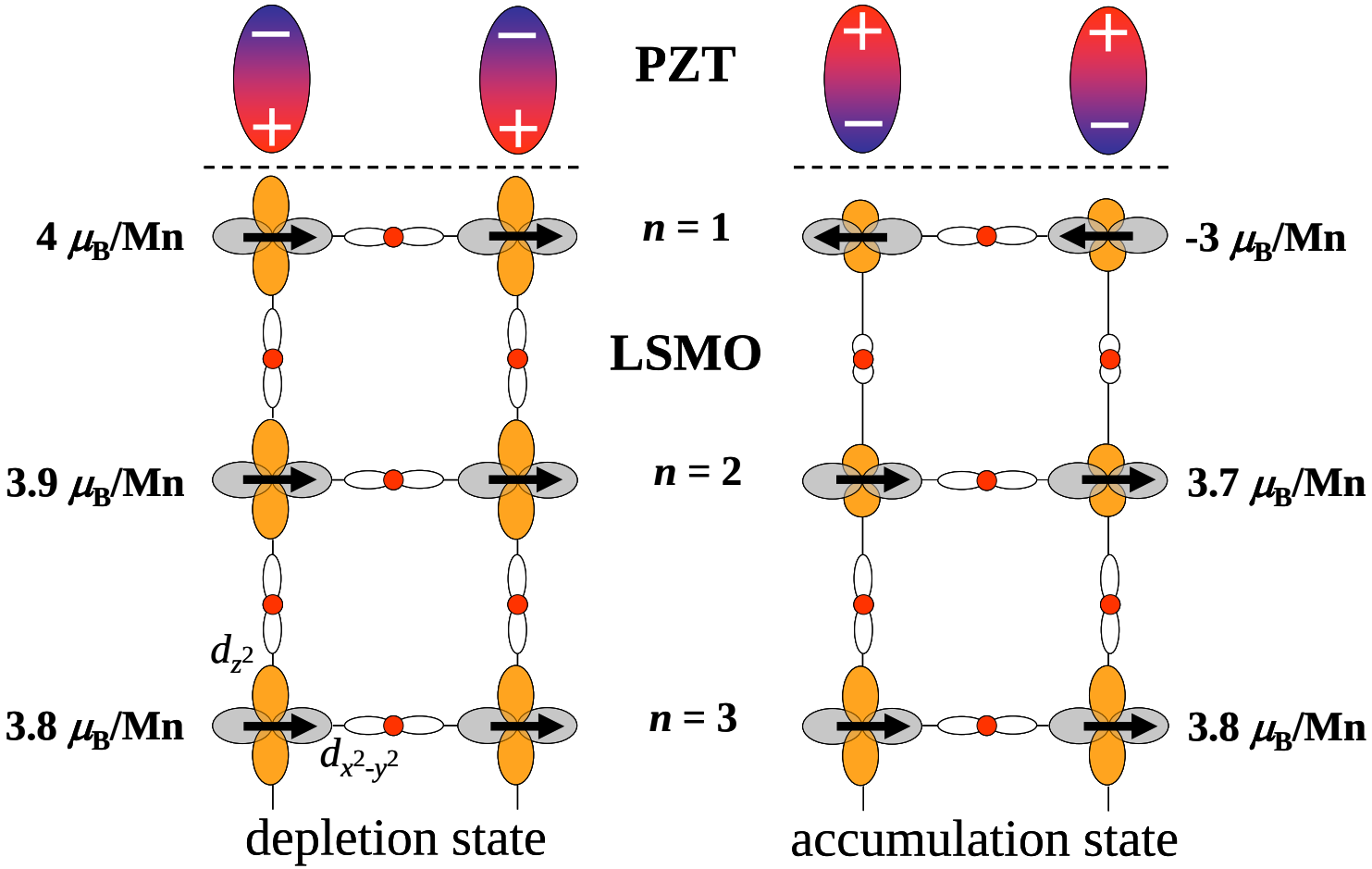


α ~ 6 Oe cm / kV

Molegraaf *et al*, Adv. Mater. 21 (2009) 3470
Vaz *et al*, APL 97 (2010) 042506

Vaz *et al*, PRL 104 (2010) 127202

Atomic & magnetic configuration

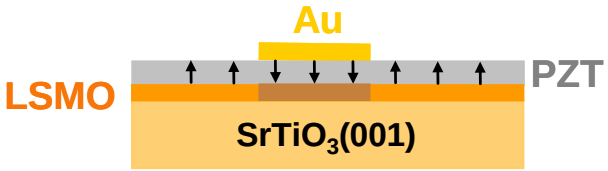


ΔM = 0.6 μ_B/Mn

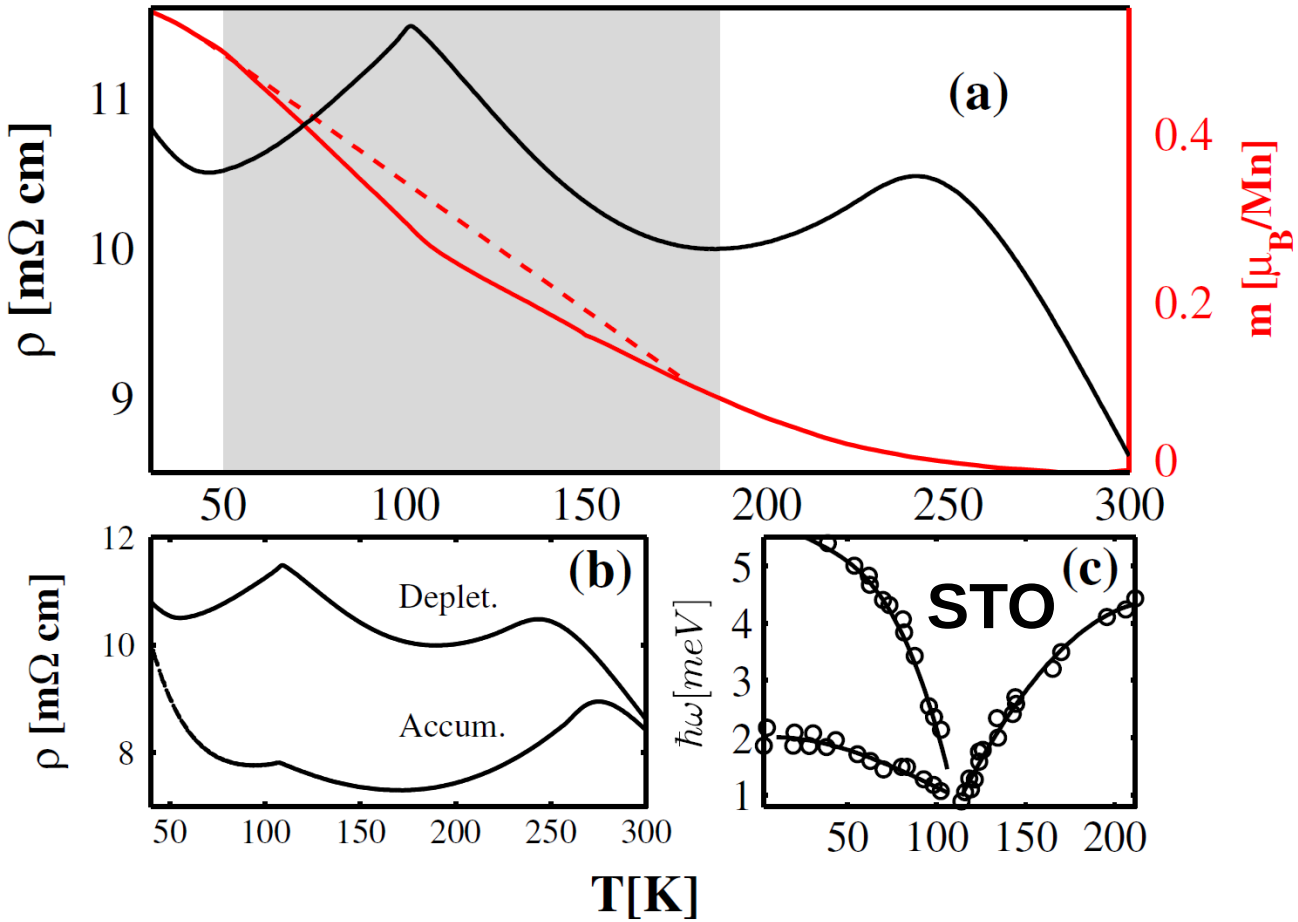
Burton and Tsymbal, PRB 80 (2009) 174406

Vaz *et al*, PRL 104 (2010) 127202

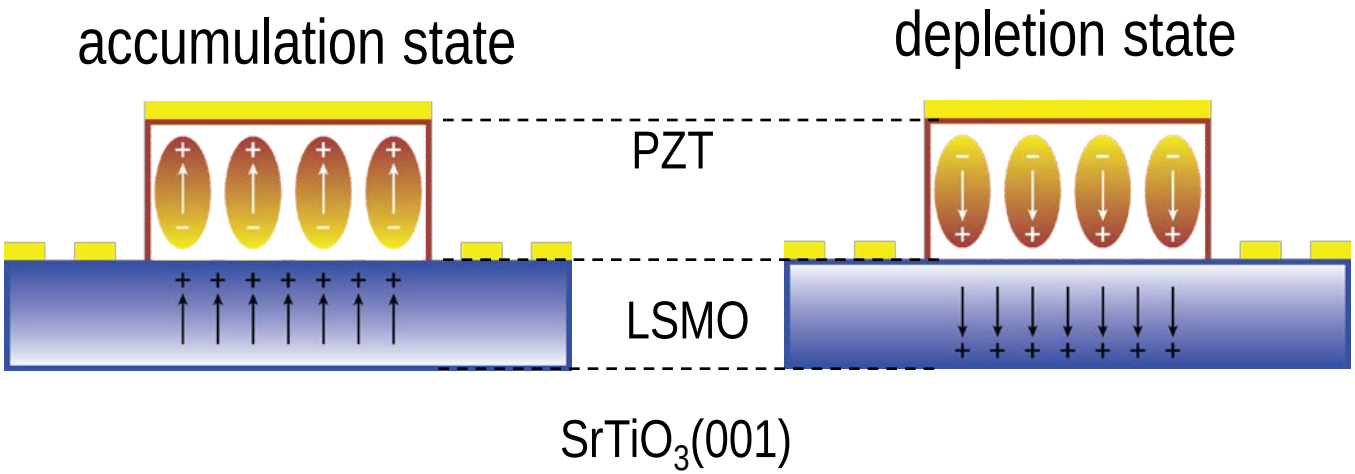
Resonant phonon coupling to $SrTiO_3$

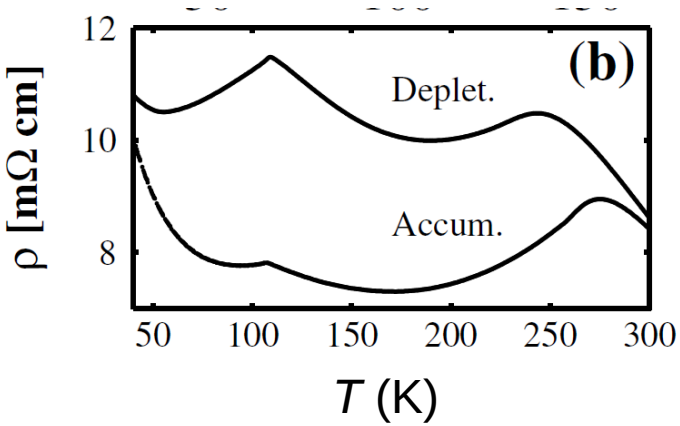


PZT/11 u.c. $La_{0.53}Sr_{0.47}MnO_3/SrTiO_3(001)$



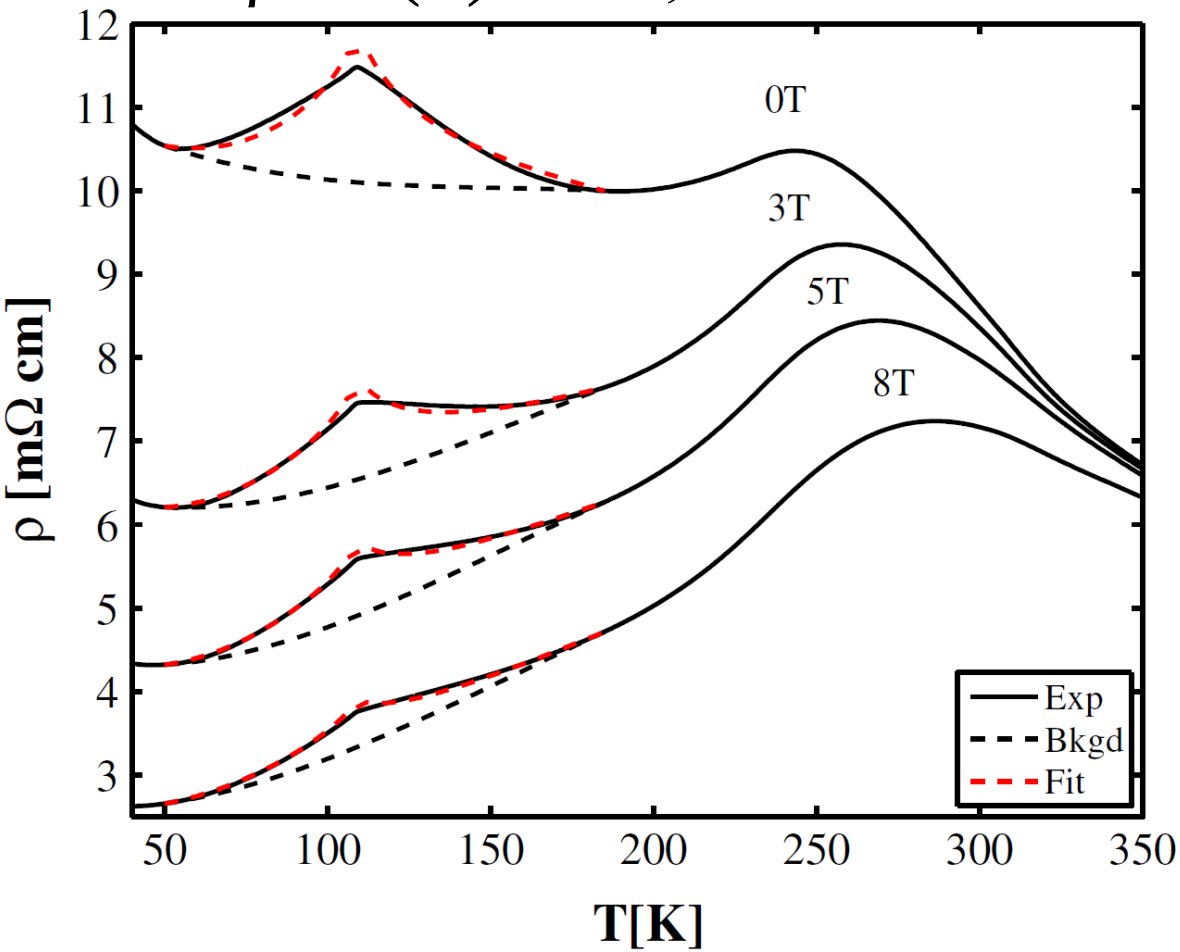
Rapid decay away from interface





Modelling the resistivity data

$\rho \sim c(B)ne^{-2z/\lambda}$, λ = 1.8 u.c



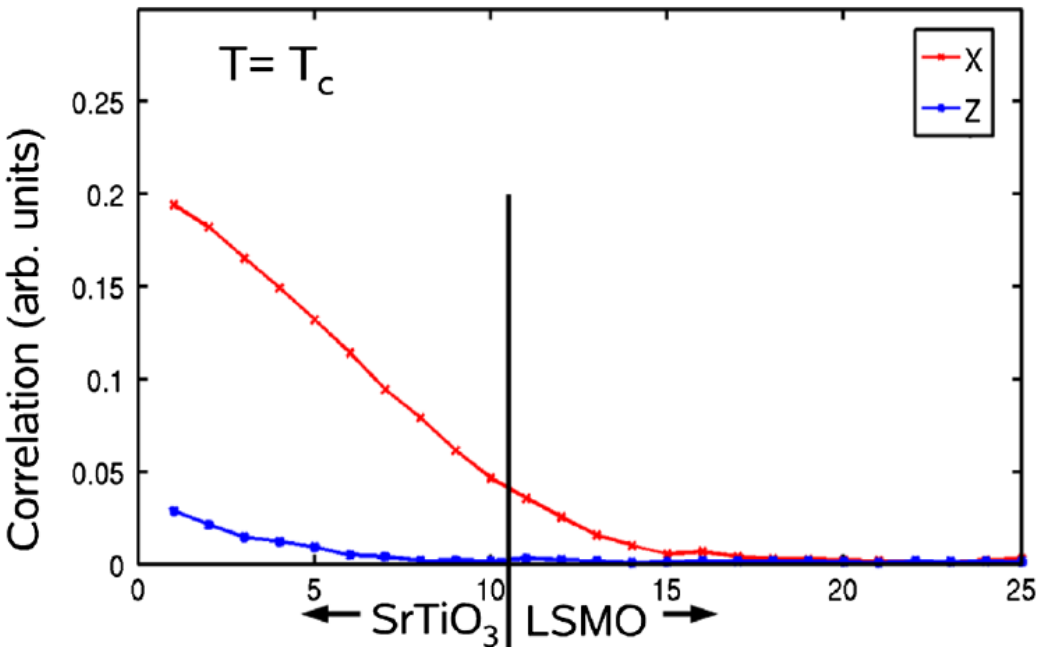
Segal, Garrity, Vaz, *et al*, PRL 107 (2011) 105501

Motions of the TiO_6 octahedra couple to MnO_6

Resistivity modified through:

(i) *static* changes in electronic structure (m_{ij}^{-1})

(ii) *dynamic* changes due to enhanced phonon scattering (t)

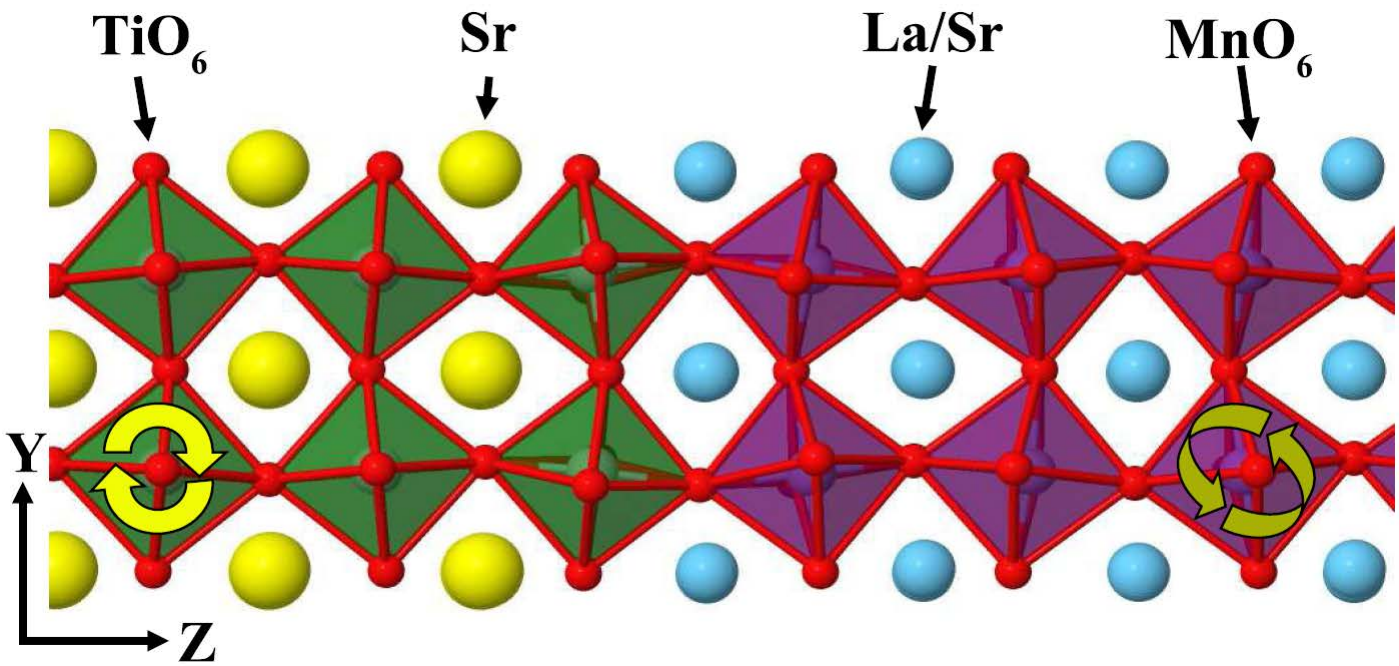


Ab initio calculations:

- Changes in octahedra angles cannot explain resistivity change
- Oxygen motions at LSMO interface become correlated with those deep in the $SrTiO_3$ at *T*c
- Decay length of correlations ~2.3 u.c.

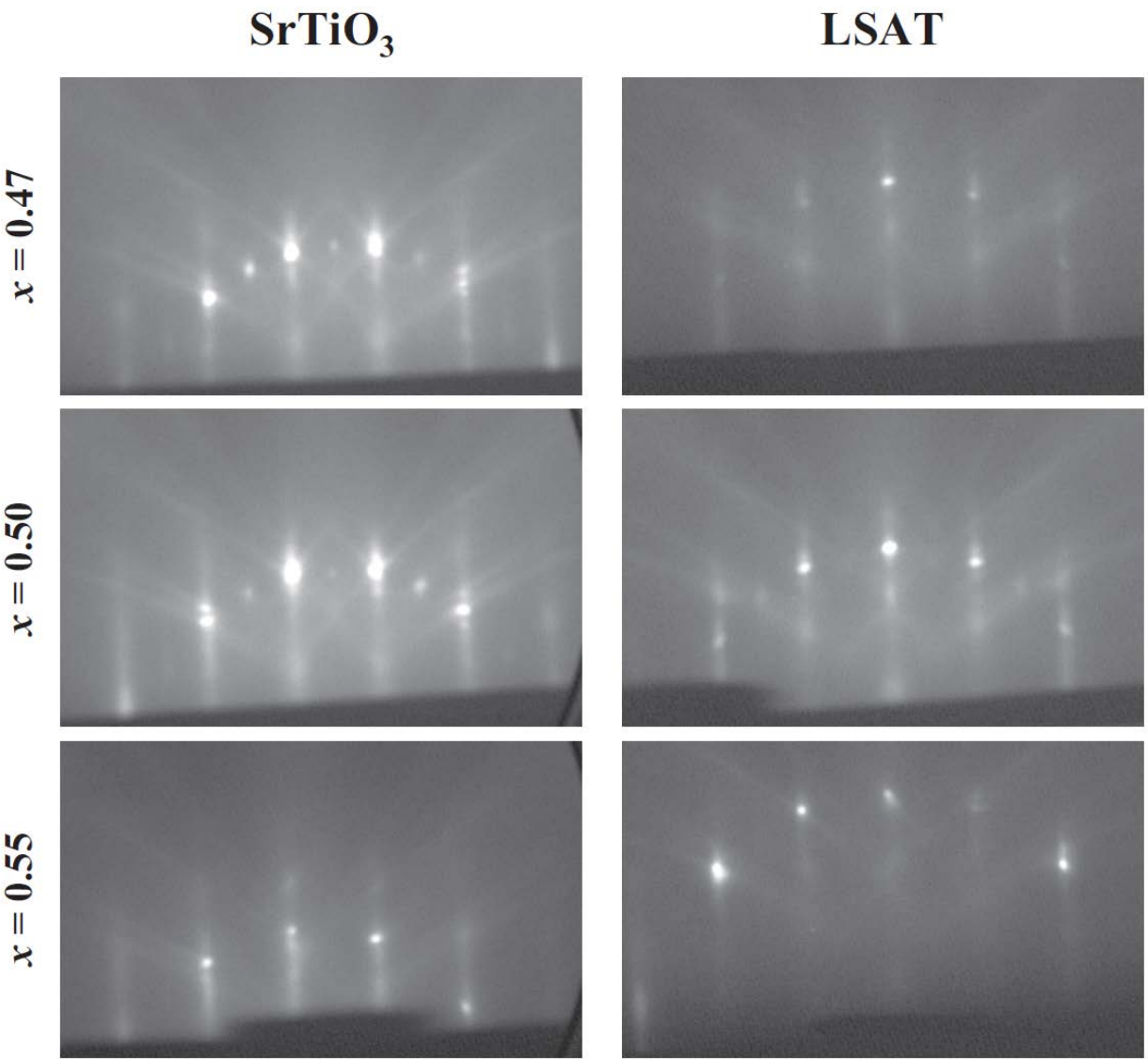
Segal, Garrity, Vaz, *et al*, PRL 107 (2011) 105501

Resonant coupling to $SrTiO_3$ soft phonons

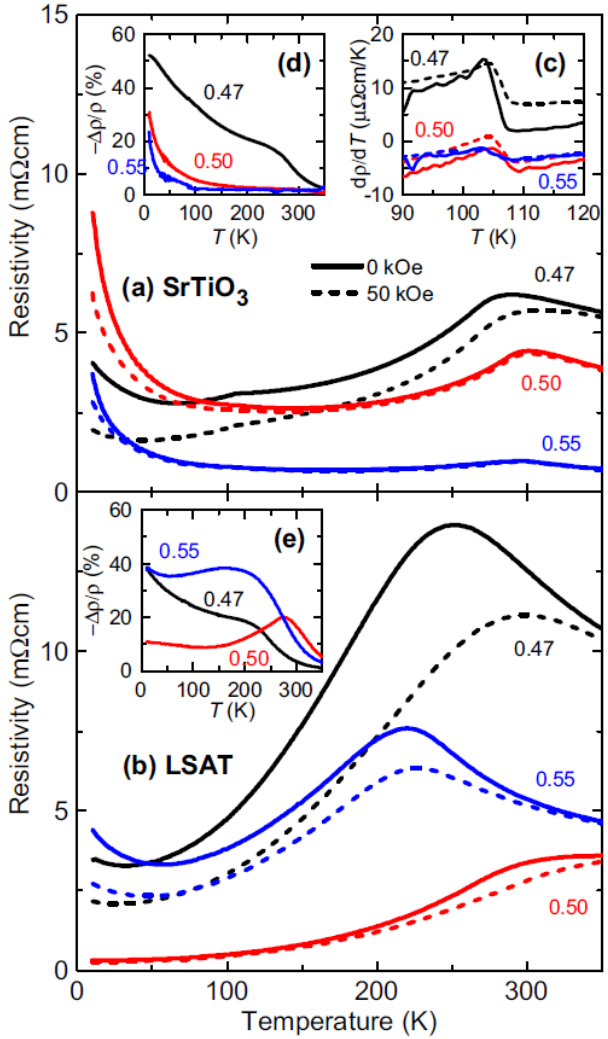


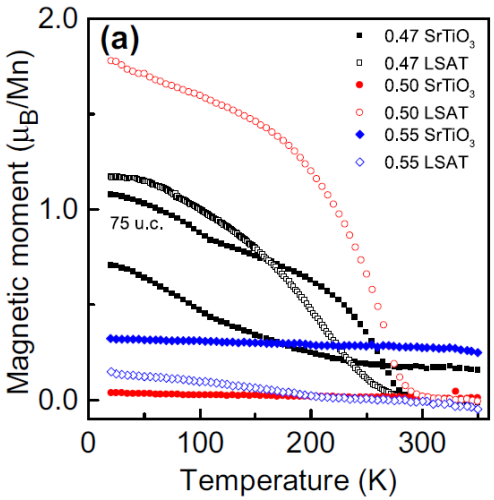
Motions of the TiO_6 octahedra couple to MnO_6, inducing *dynamic* changes due to enhanced phonon scattering (*t*)

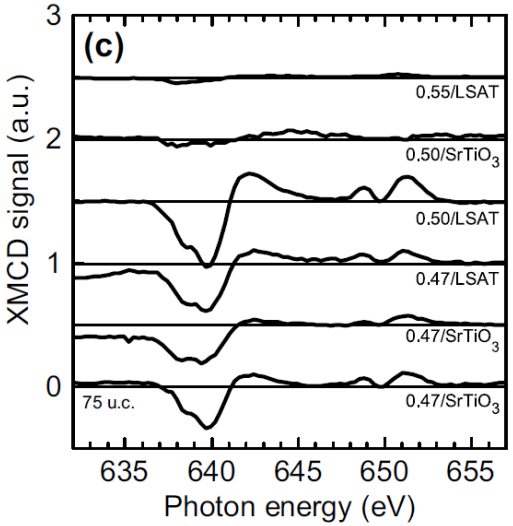
$La_{1-x}Sr_xMnO_3$ thin films at near half doping



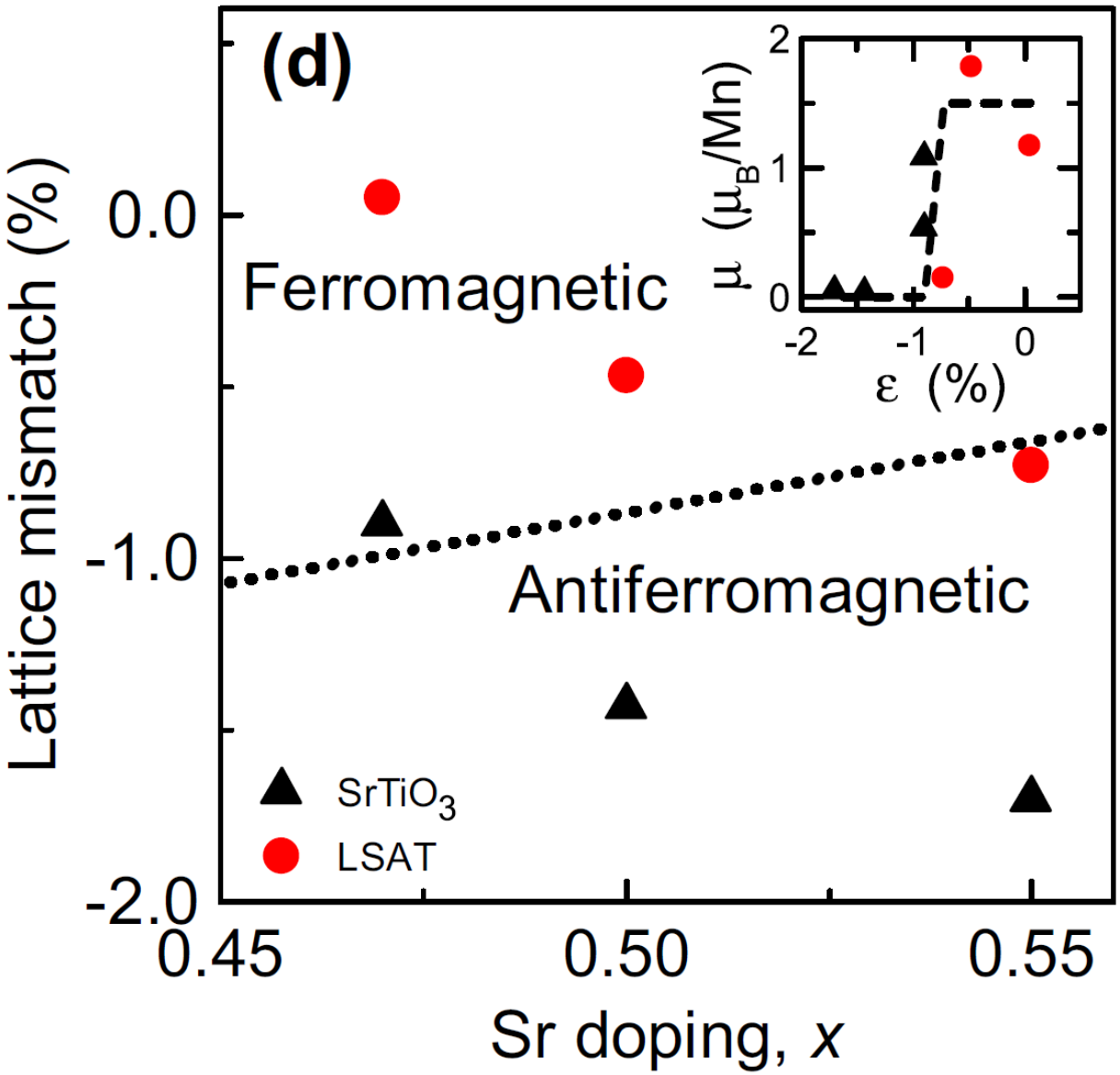
Transport and magnetic properties



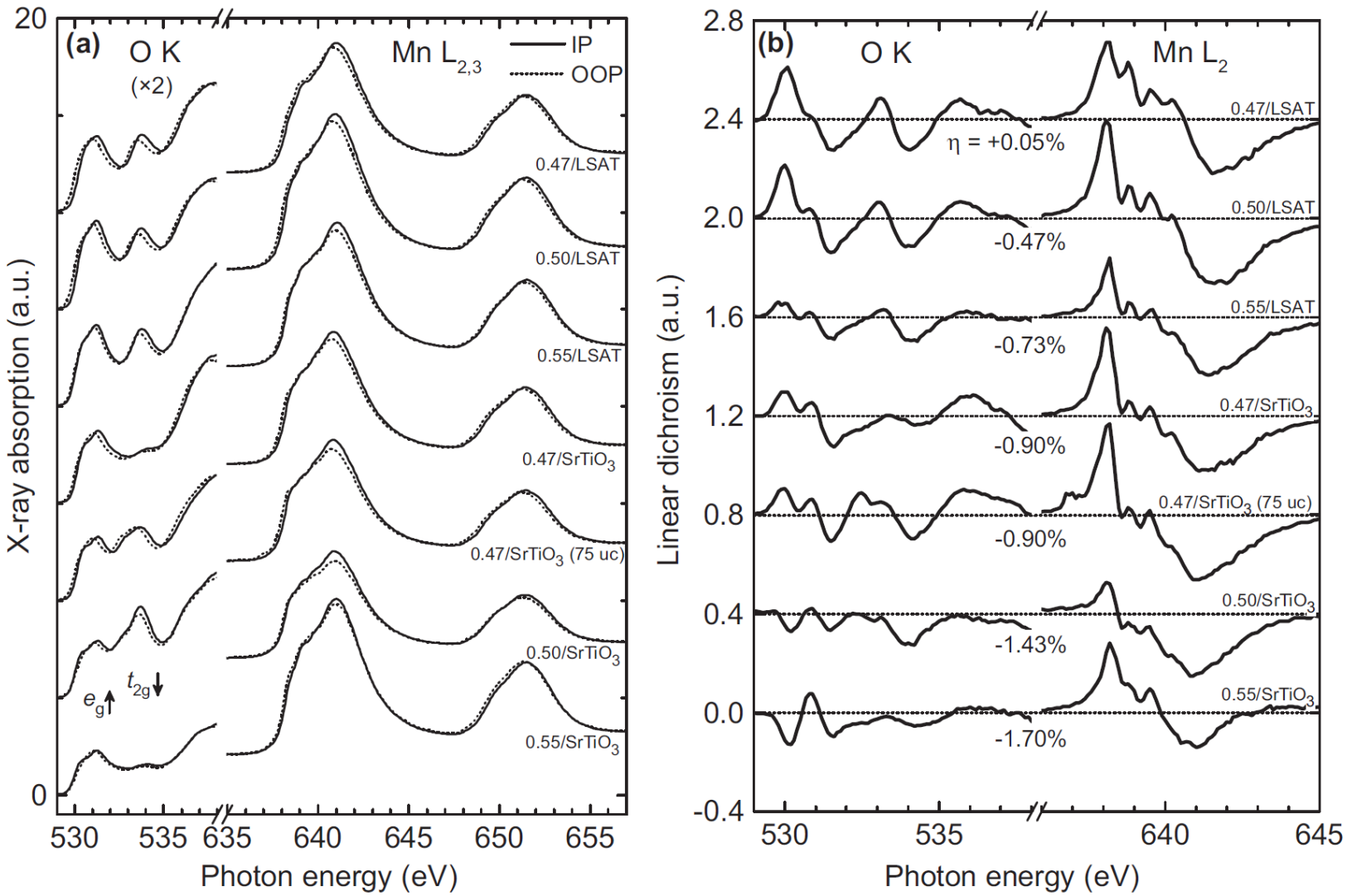




Phase diagram for LSMO thin films at near ½ doping

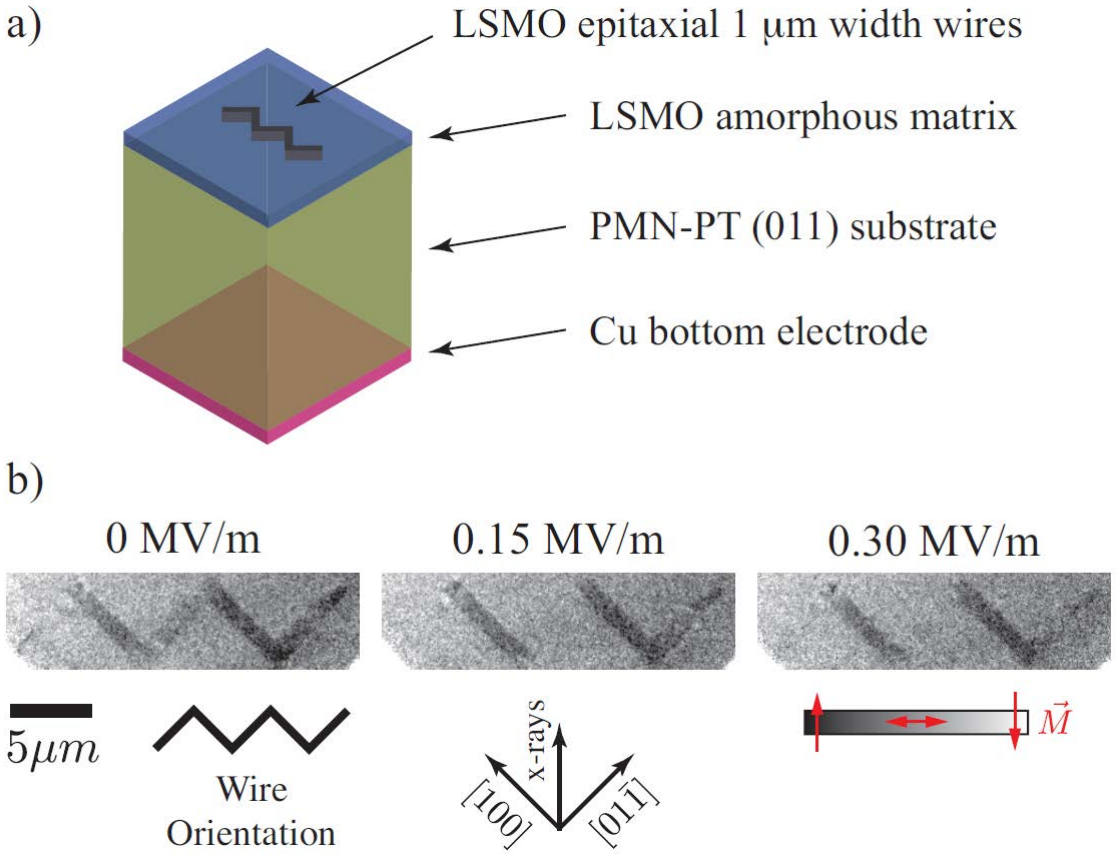


$La_{1-x}Sr_xMnO_3$ thin films at near half doping



Vaz *et al.*, PRB 90, 024414 (2014)

Strain-induced magnetoelectric coupling



M. Buzzi, C. A. F. Vaz, J. Raabe, and F. Nolting, unpublished (2015)

…artificial multiferroics: onset of new coupling at oxide interfaces

…demonstration of a phonon resonant coupling at the LSMO/$SrTiO_3$ interface

…electronic state of LSMO at ½ doping very sensitive to strain and charge doping

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Mein Dank geht an

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M. Buzzi, F. Nolting, J. Raabe (PSI)