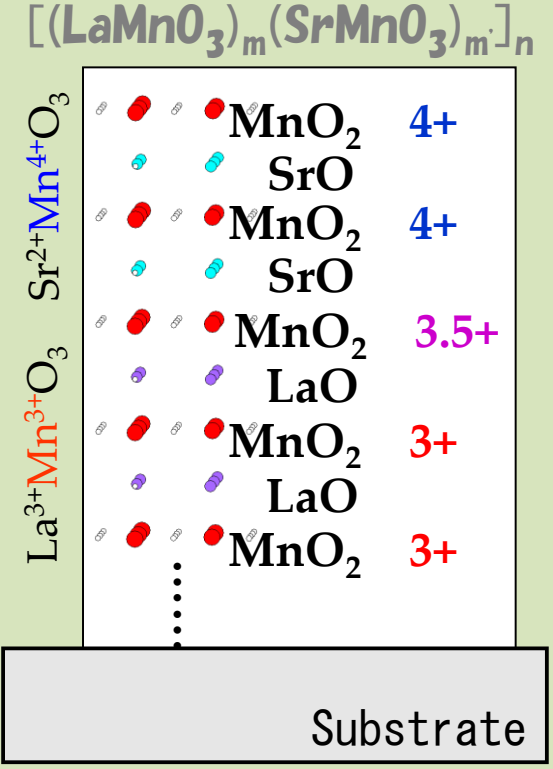
- 放射光を用いたキャラクタリゼーション -

マンガン系人工超格子における電荷・磁気状態の研究



Condensed matter research center (CMRC)
Photon Factory, IMSS, KEK

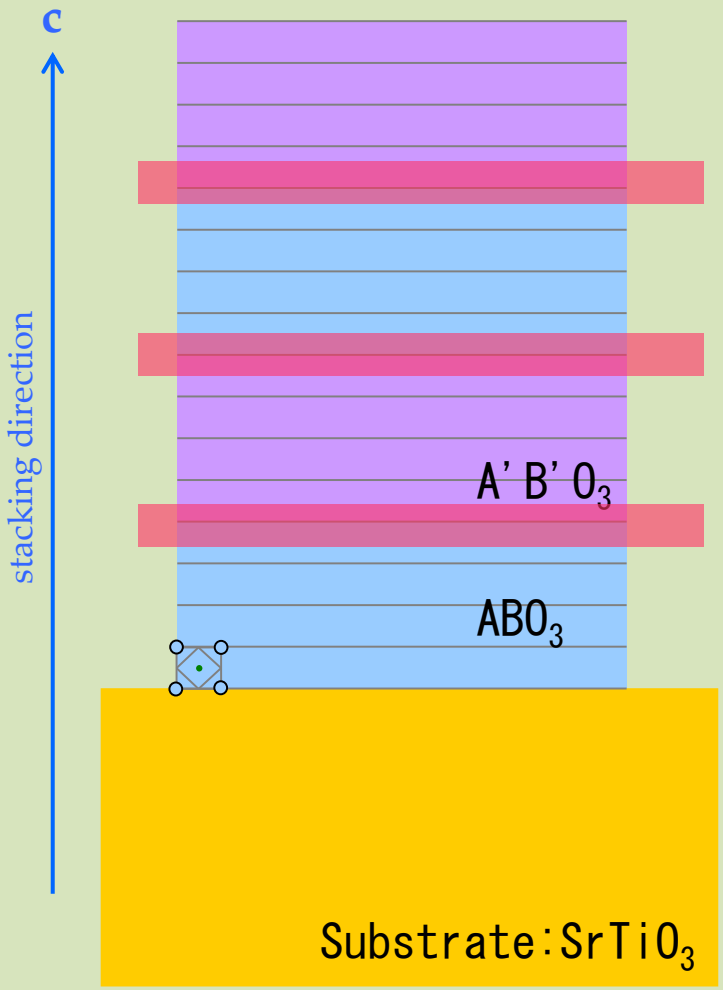
中尾裕則

Outline

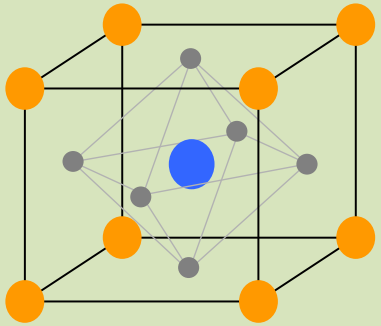
- 研究背景
- 放射光を用いた薄膜、人工格子の研究について
- 中性子磁気散乱による磁気構造の研究の現状

$(LaMnO_3)_2(SrMnO_3)_2$ の巨大磁気抵抗効果

人工超格子：自由な積層構造の設計による物性制御



結晶（ABO_3）



ペロブスカイト構造

多様な物性

誘電体
強磁性体
反強磁性体
超伝導体

巨大磁気抵抗効果
電気磁気効果

任意の積層構造の作製

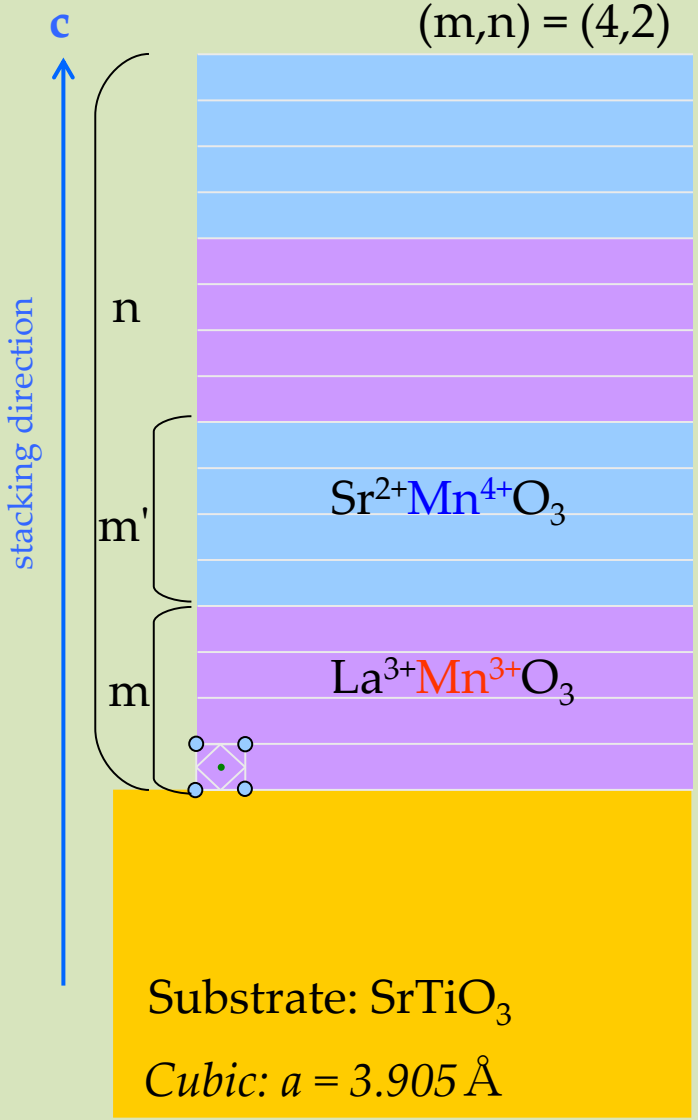
電荷・スピン・軌道・格子の制御

新奇物性の探索や、
自由なデバイス設計の可能性

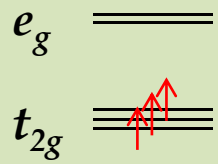
ヘテロ界面で作り出される新たな電子状態

人工超格子: $[(LaMnO_3)_m(SrMnO_3)_{m'}]_n$

Perovskite structure



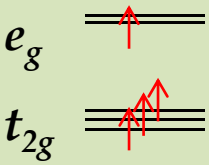
$Sr^{2+}Mn^{4+}O_3$ G-type AF



Mn^{4+}

Band insulator

$La^{3+}Mn^{3+}O_3$ A-type AF

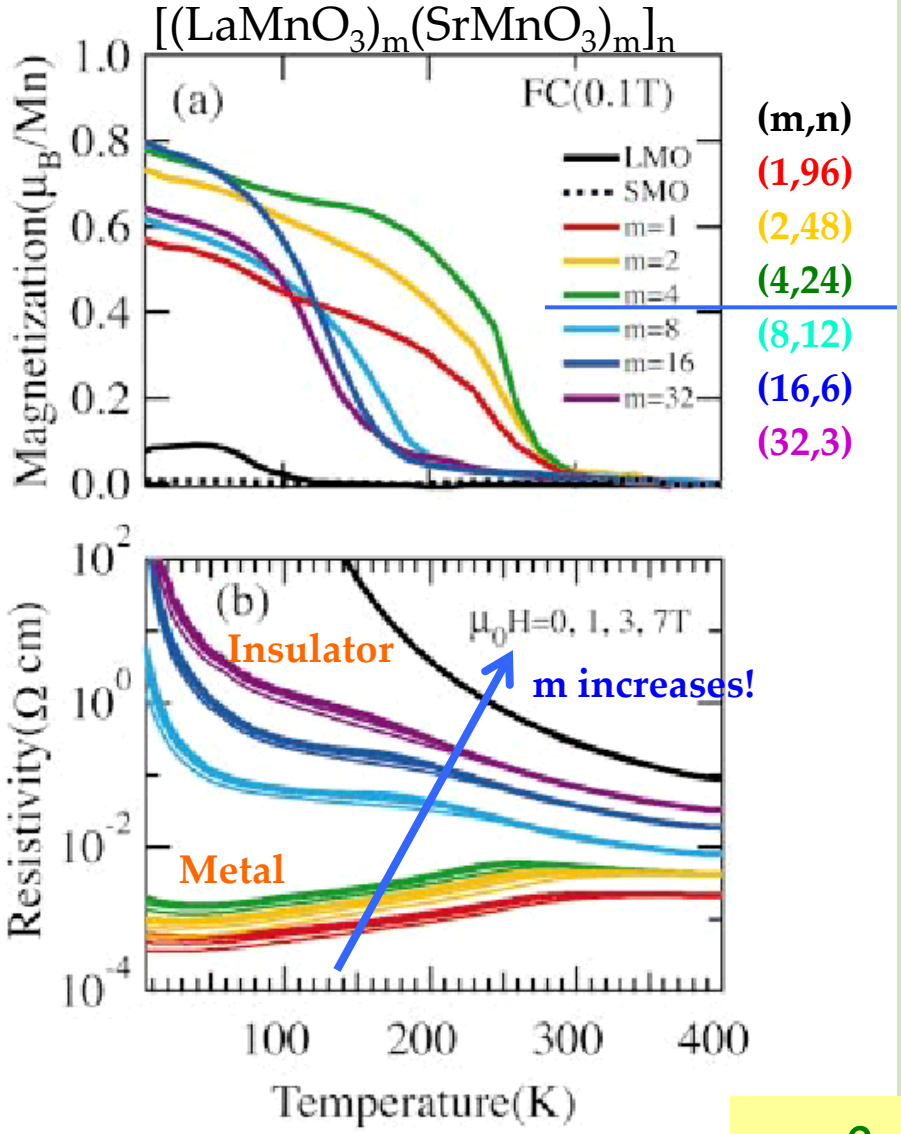


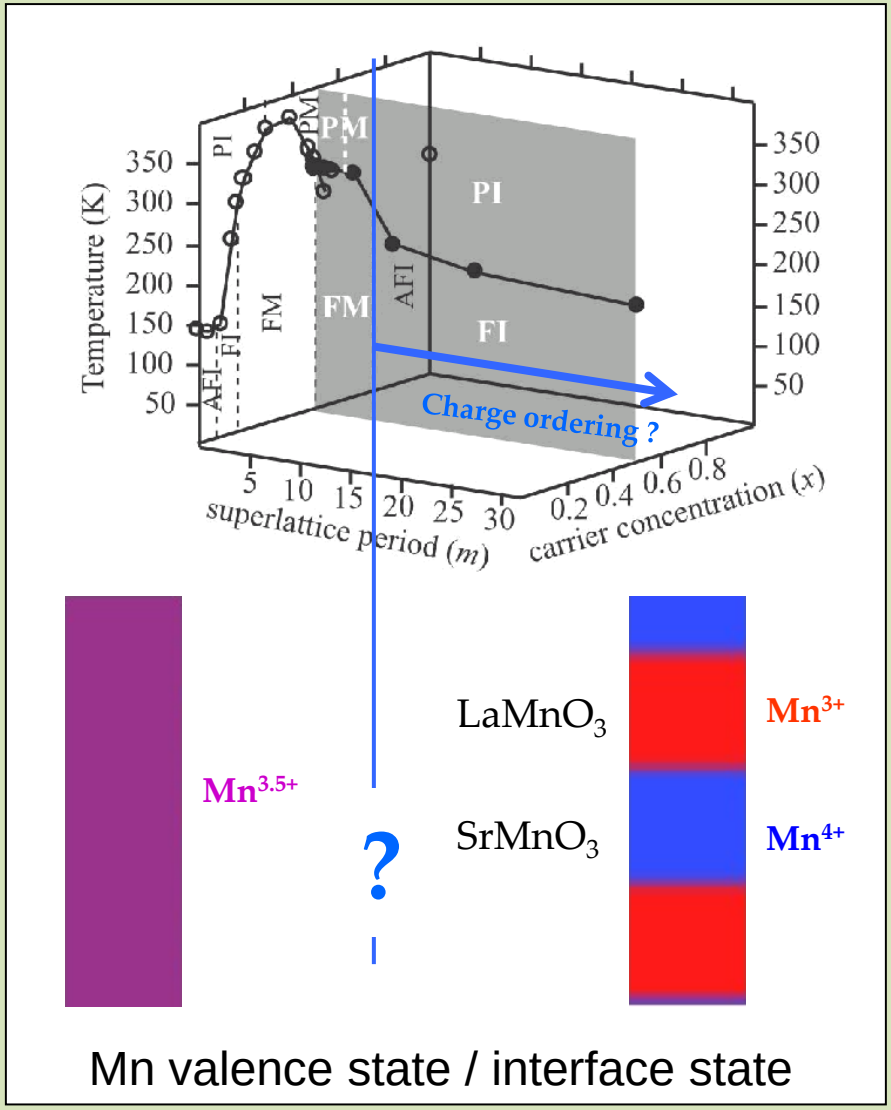
Mn^{3+}

Mott insulator

電荷変調構造の制御 ⟶ 新奇物性？

人工超格子: $[(LaMnO_3)_m(SrMnO_3)_{m'}]_n$

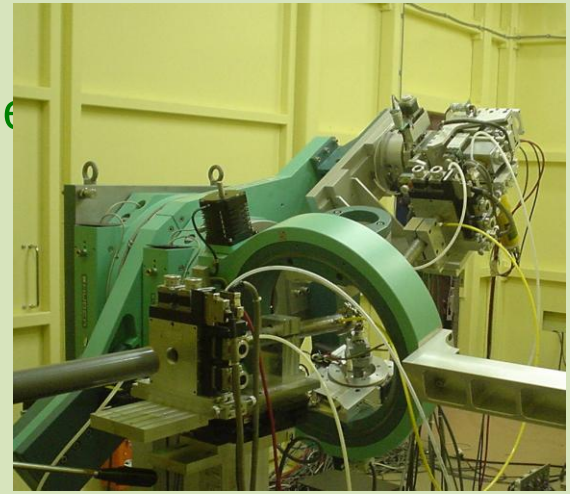




T. Koida *et al.*, PRB **66** (2002) 144418

Specific character in superlattice

- Resonant x-ray scattering study of the superlattices to clarify the charge distribution of the Mn ion
- Evaluation of the superlattice structure



Experiments

- Synchrotron x-ray scattering
- Diffraction pattern along the stacking direction at 6.52 keV
  ⟶ Superlattice structure (atomic coordinations)
- Energy dependence of the scattering intensity near Mn *K*-edge (~ 6.55 keV)
  ⟶ Charge distribution of Mn ion

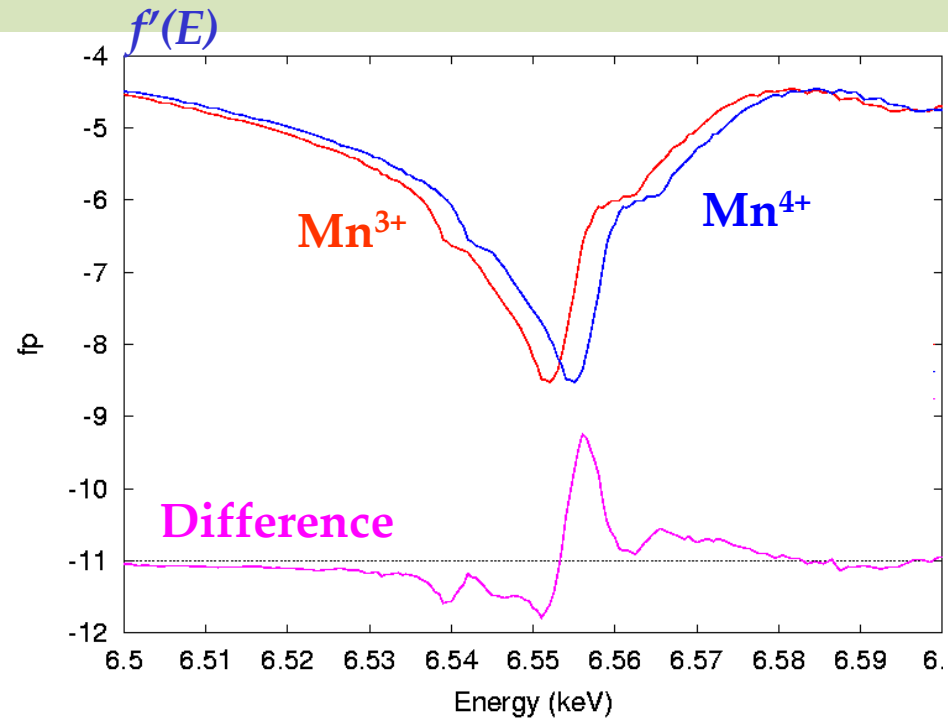
$$I(E,hk\ell) = |F(E,hk\ell)|^2$$

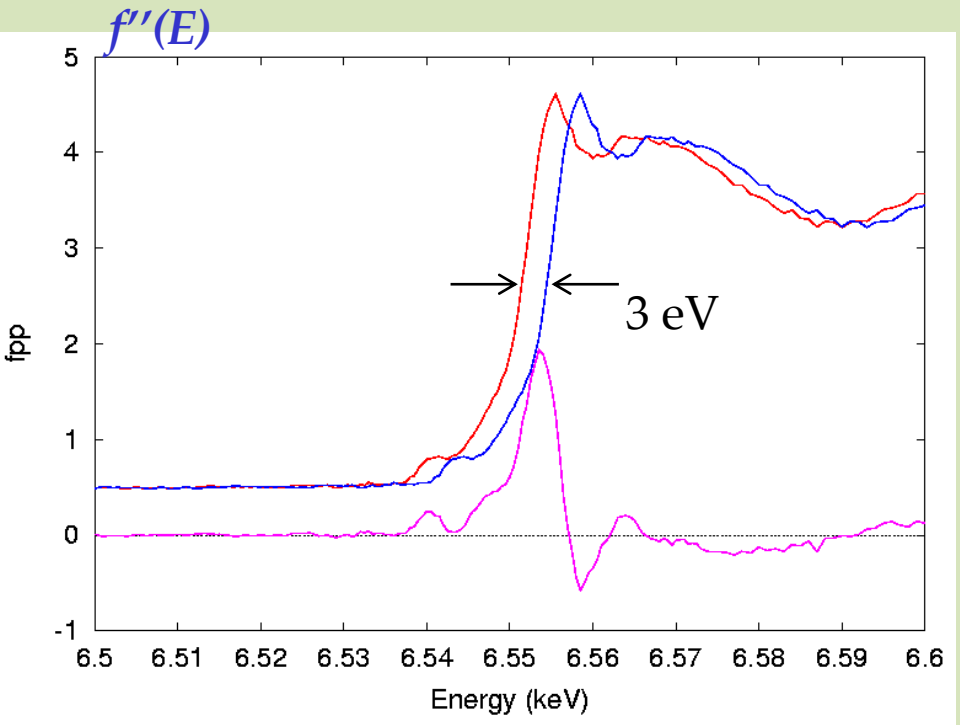
$$F(E,hk\ell) = \sum_i f_i(E) exp[-2\pi i(hx_i + ky_i + \ell z_i)]$$

$$f(E) = f_0 + f'(E) + if''(E)$$

X-ray anomalous scattering factor

X-ray anomalous scattering factor of Mn ion





- Energy dependence of the scattering intensity
  near Mn *K*-edge （~ 6.55 keV）

⟶ Charge distribution of Mn ion ⟵

$$I(E,hk\ell) = |F(E,hk\ell)|^2$$

$$F(E,hk\ell) = \sum_i f_i(E) exp[-2\pi i(hx_i + ky_i + \ell z_i)]$$

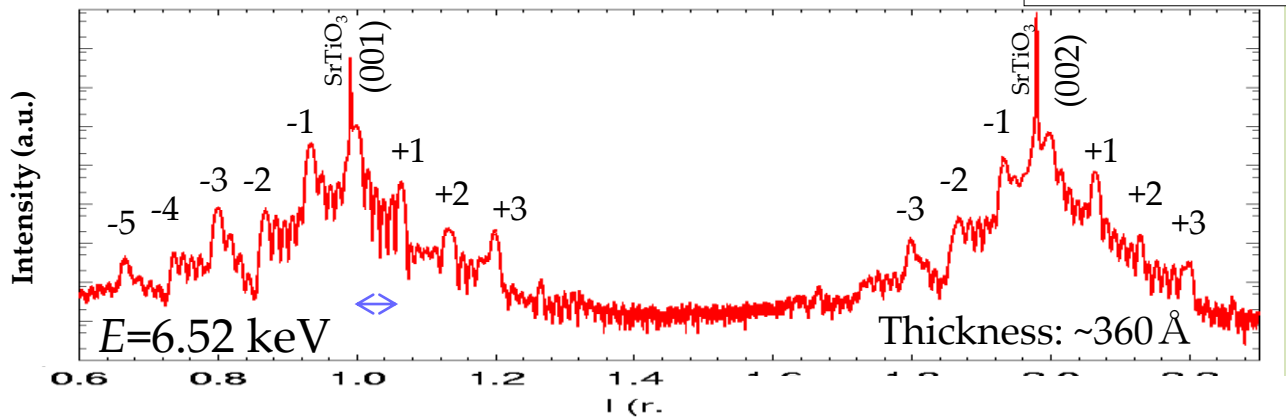
$$f(E) = f_0 + f'(E) + if''(E)$$

X-ray anomalous scattering

Crystal structure of superlattice

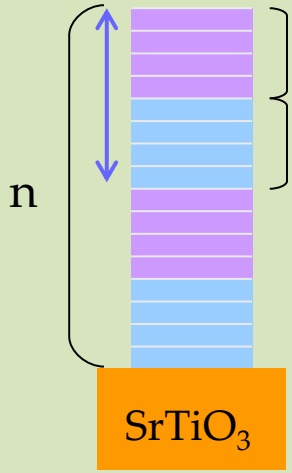
$$I(E,hk\ell) = |F(E,hk\ell)|^2$$

$$F(E,hk\ell) = \sum_i f_i(E) exp[-2\pi i(hx_i + ky_i + \ell z_i)]$$



$[(LaMnO_3)_m(SrMnO_3)_m]_n$

(m,n) = (8,6)

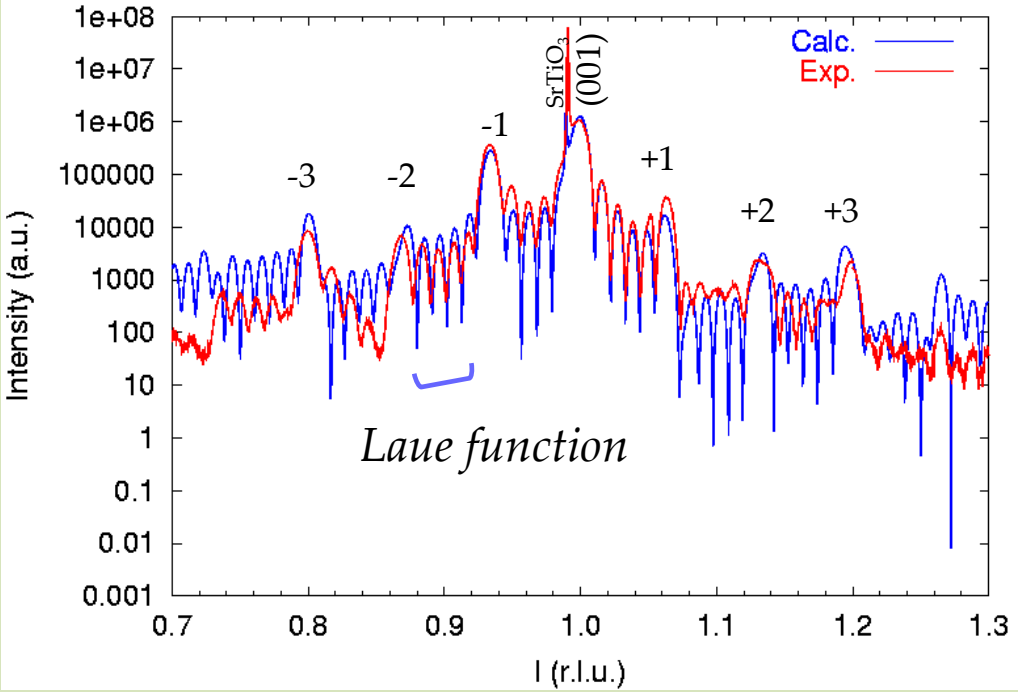


$LaMnO_3$ d_{La}

$SrMnO_3$ d_{Sr}

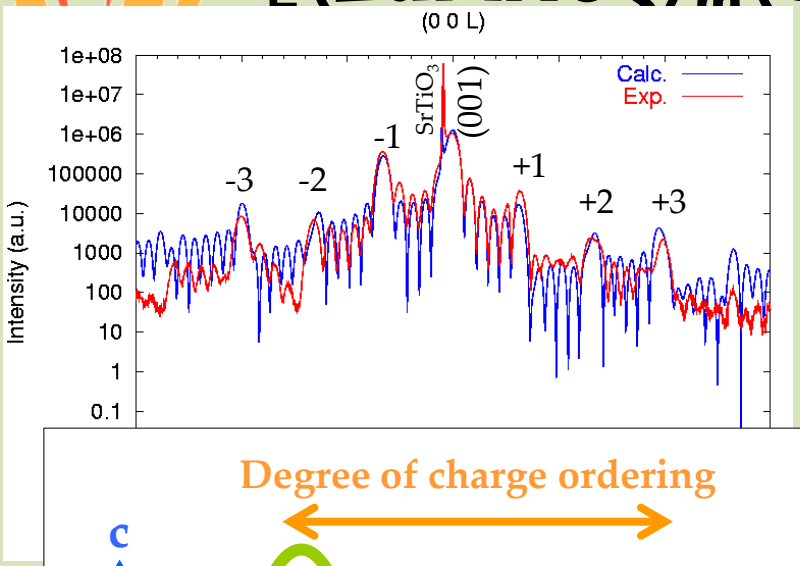
Structural deviation near interface

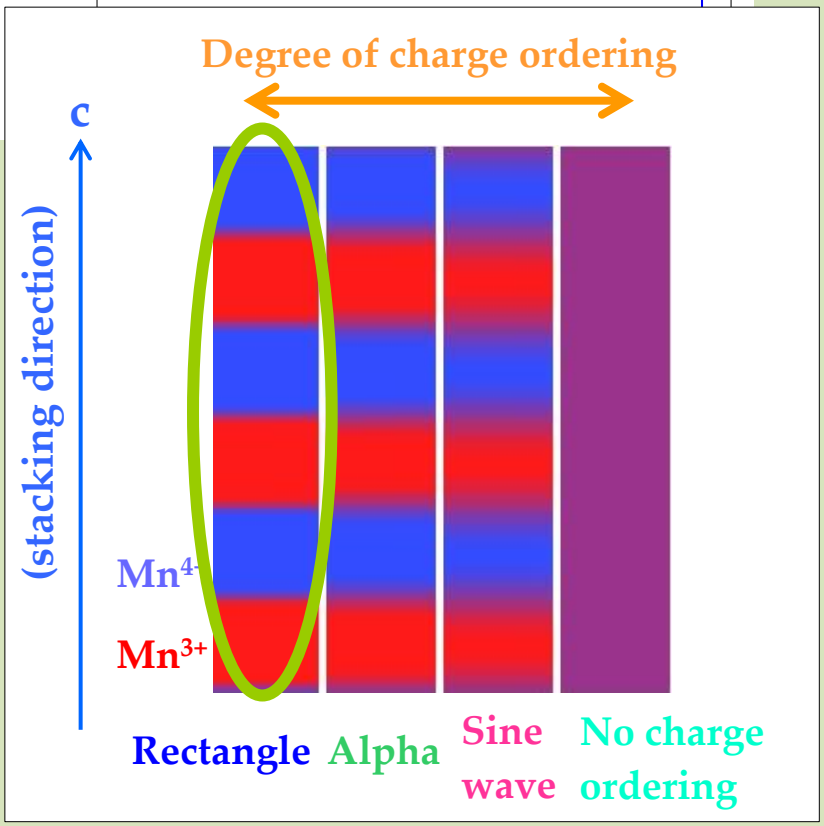
Substrate scattering

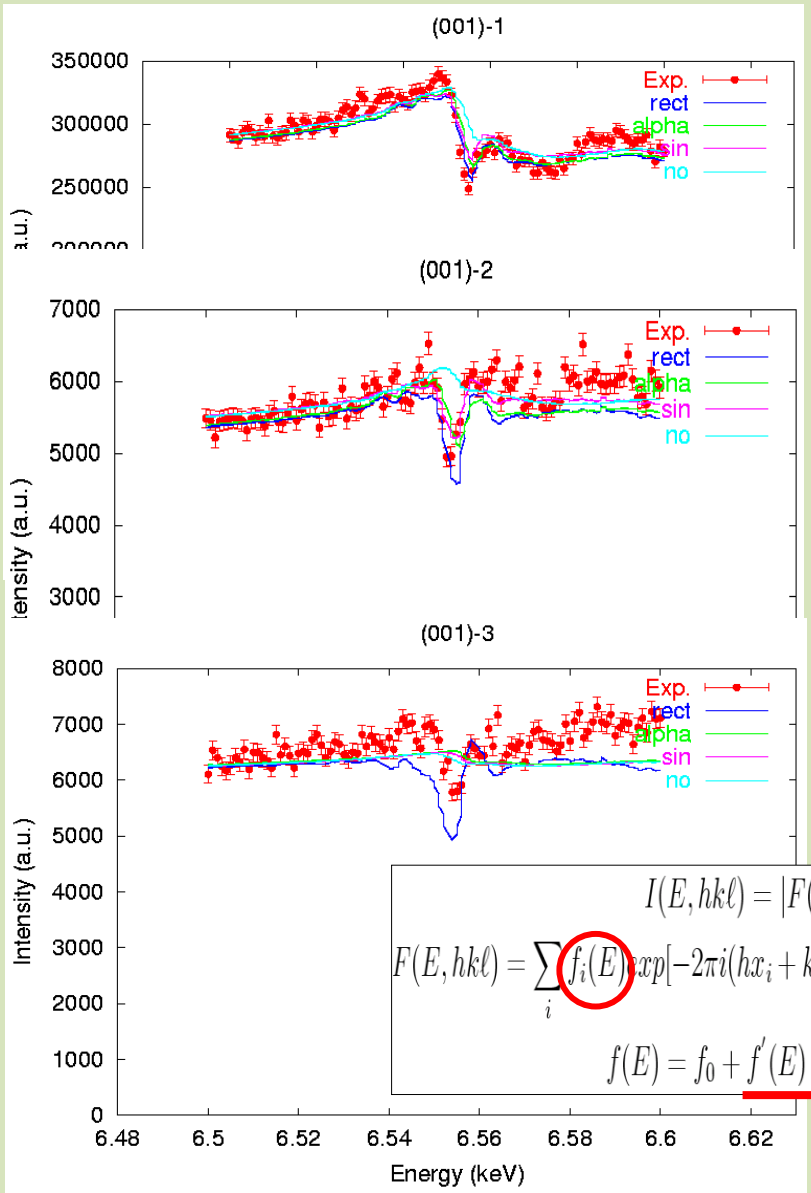


H. Nakao *et al.*, JPSJ **78** (2009) 024602.

$[(LaMnO_3)_m(SrMnO_3)_m]_n$ (m,n) = (8,6)

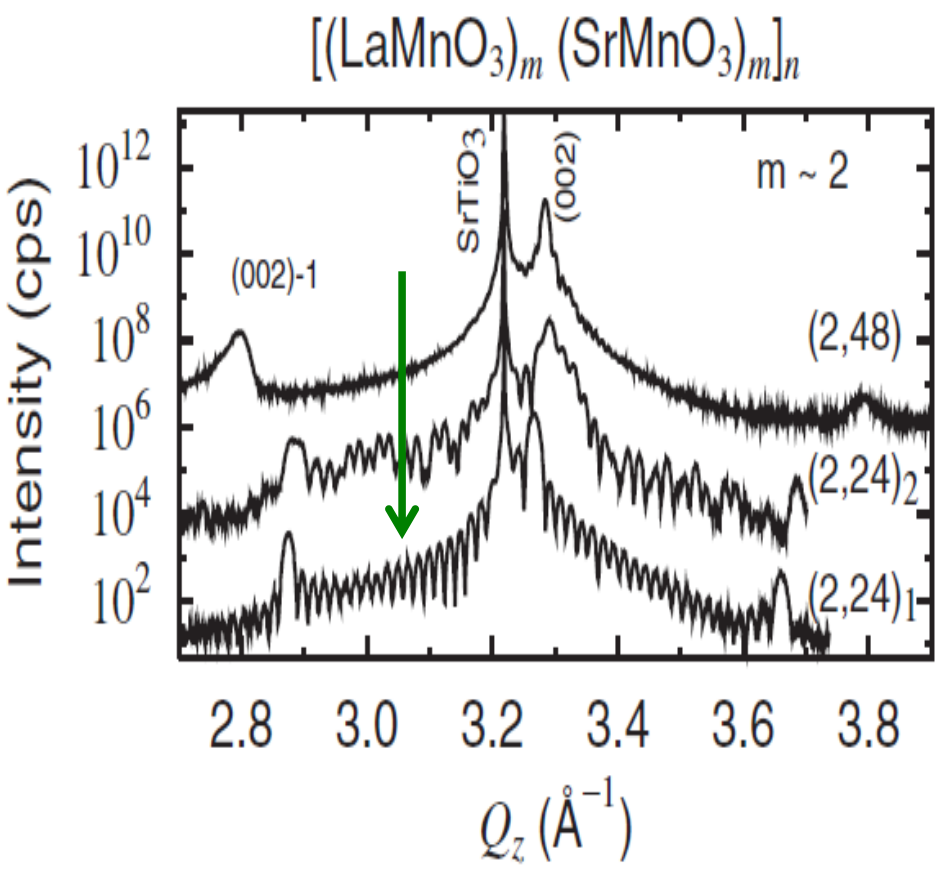


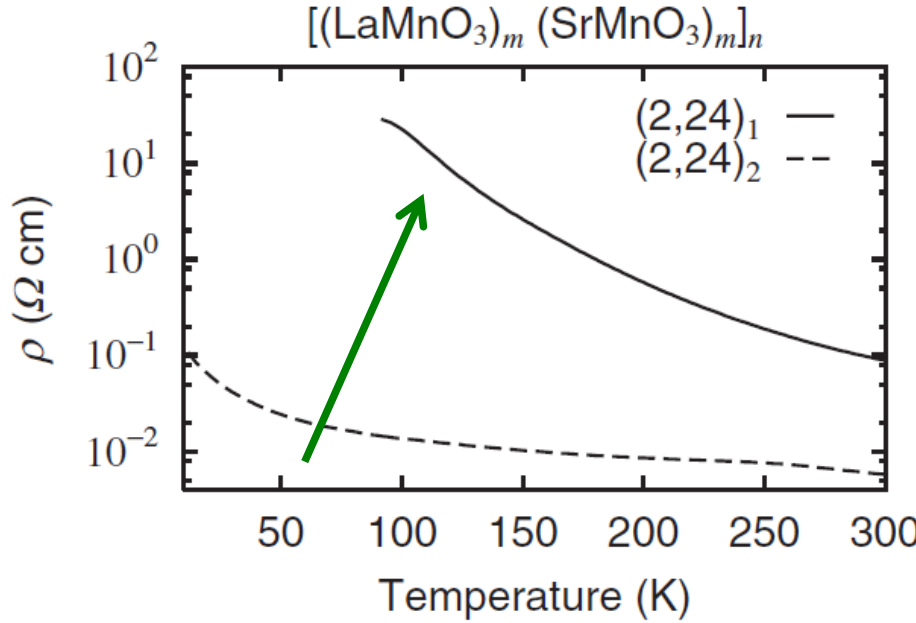


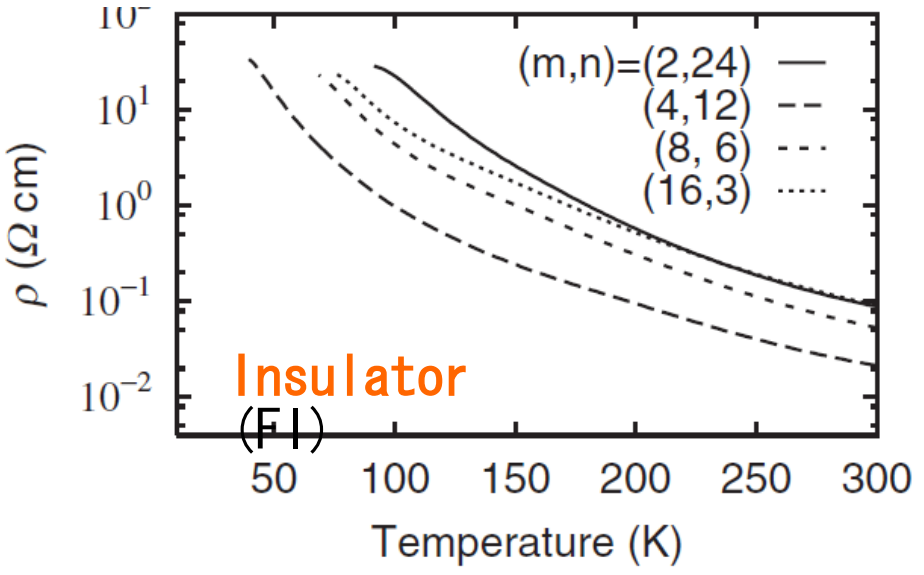


H. Nakao *et al.*, JPSJ **78** (2009) 024602.

Insulator vs. Metal



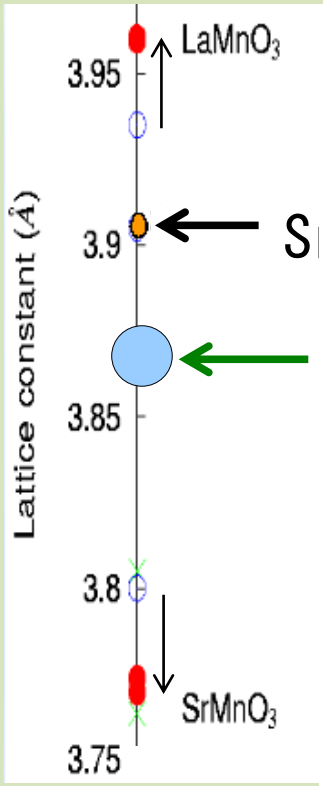


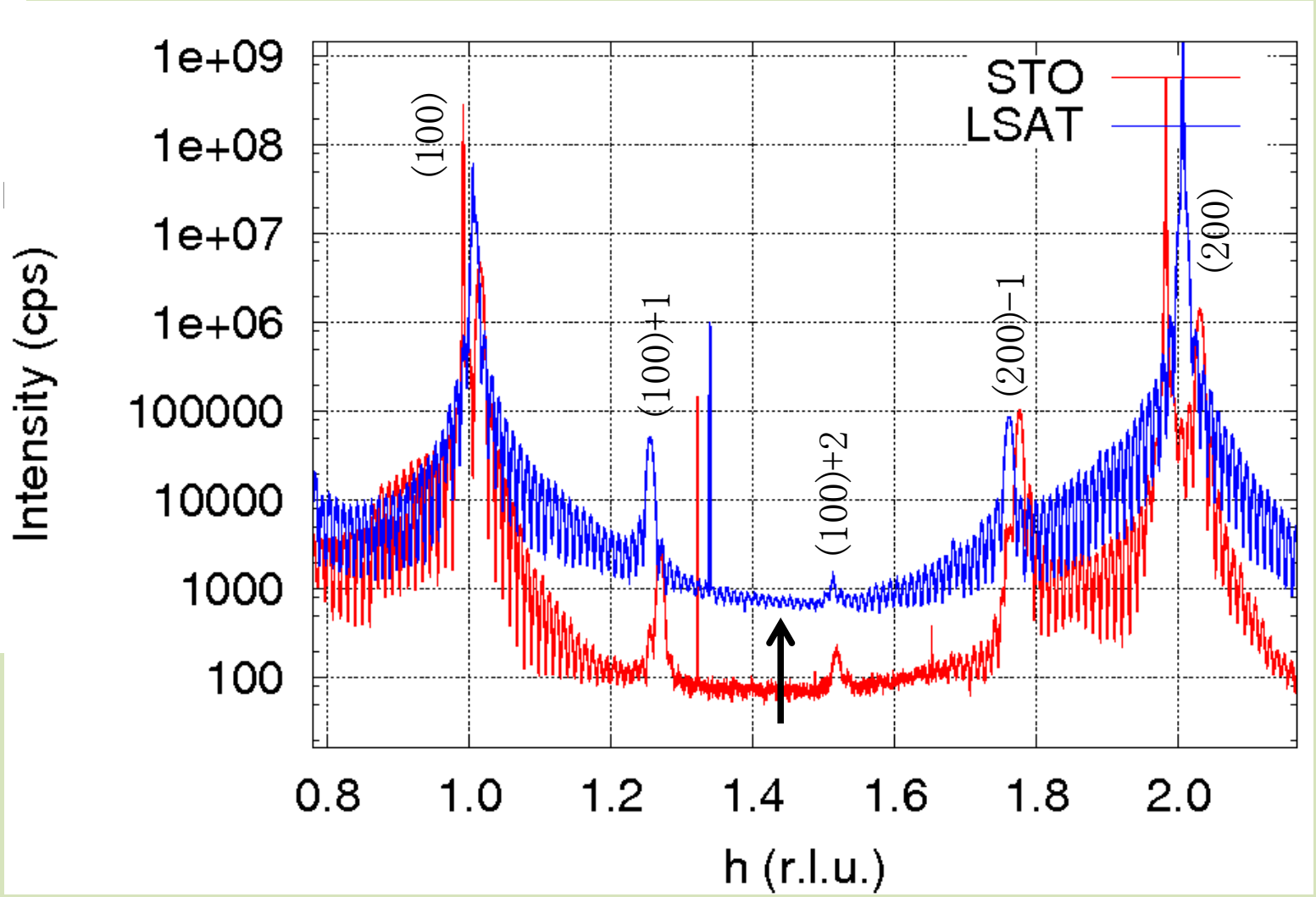


Quality of stacking structure ⇕ Conductivity

Sample quality: $SrTiO_3$ vs. LSAT

Lattice matching between film and substrate

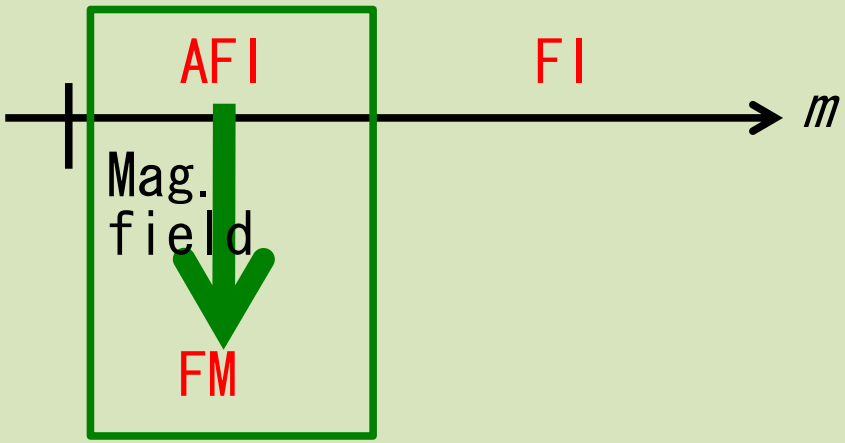


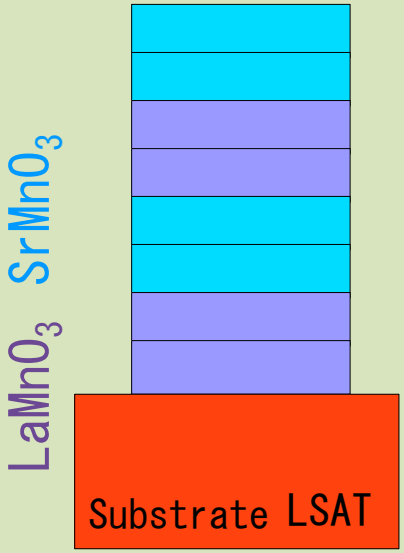


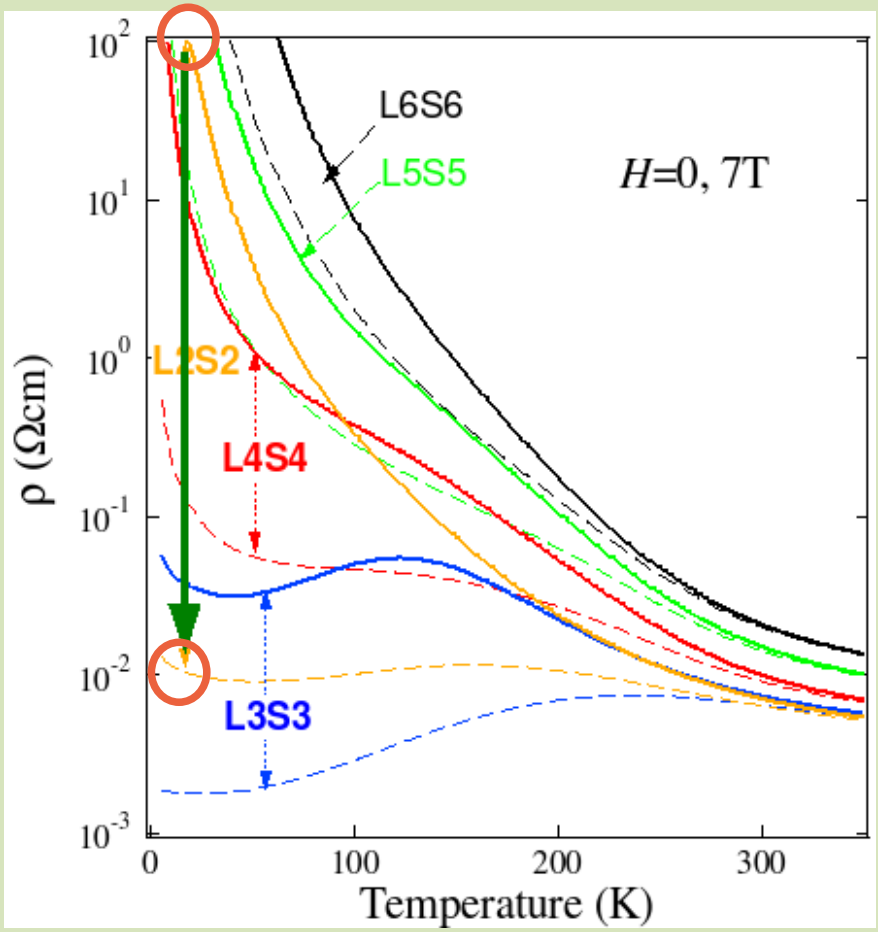
H. Yamada (AIST)

$[(LaMnO_3)_m(SrMnO_3)_m]_n$

$[(LaMnO_3)_m(SrMnO_3)_m]_n$ LSAT







m ≦ 4:

Large negative magneto-resistance

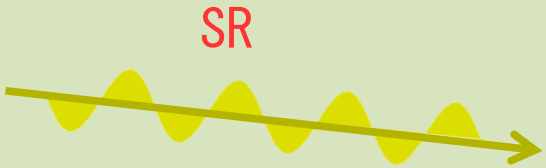
This is new phenomenon in film system.

not reported in the bulk

Study project in CMRC

- Synchrotron radiation

Resonant and non-resonant x-ray scattering
- Mn valence distribution
- Stacking structure

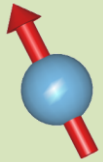


Resonant soft x-ray scattering
- Resonant magnetic scattering
- Mn3d - O2p orbital hybridization
- Modulation of electronic structure

Depth resolved XAS, XMCD (雨宮)…

- Neutron
  - Magnetic scattering (東北大 岩佐)
  - Reflectivity (JAEA 武田)

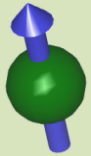
→ J-PARC



Neutron

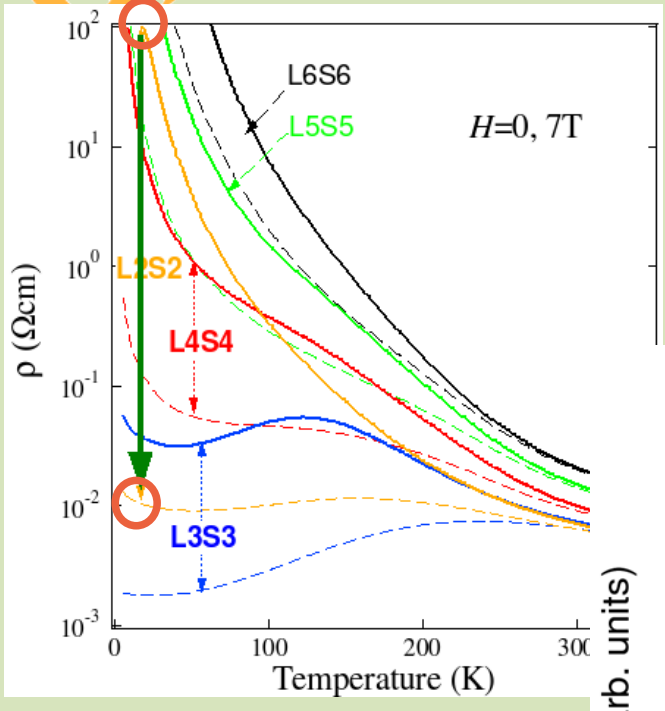
- Muon

Ultra-slow muon



Muon

Crystal structure in superlattice



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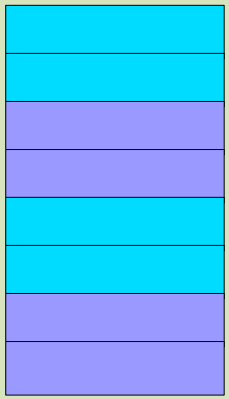
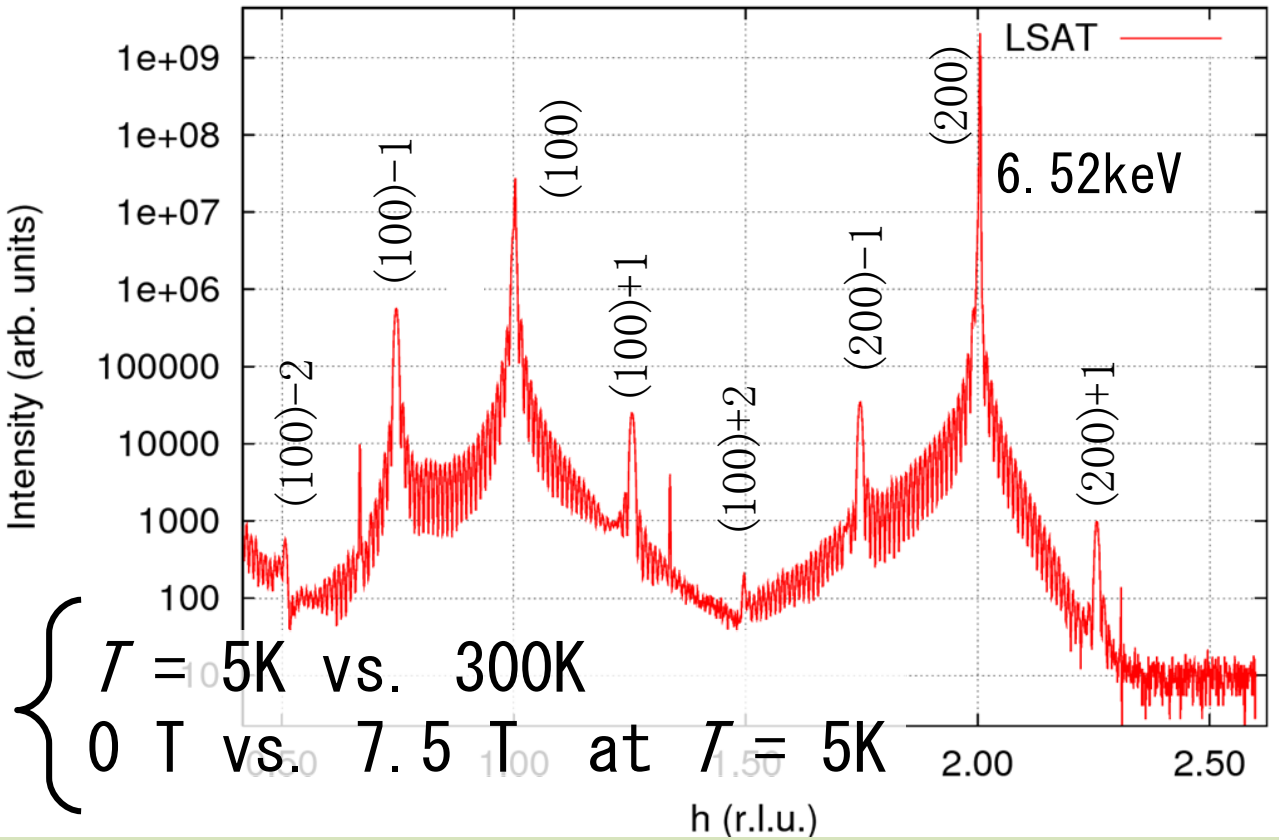


$(LaMnO_3)_2(SrMnO_3)_2$

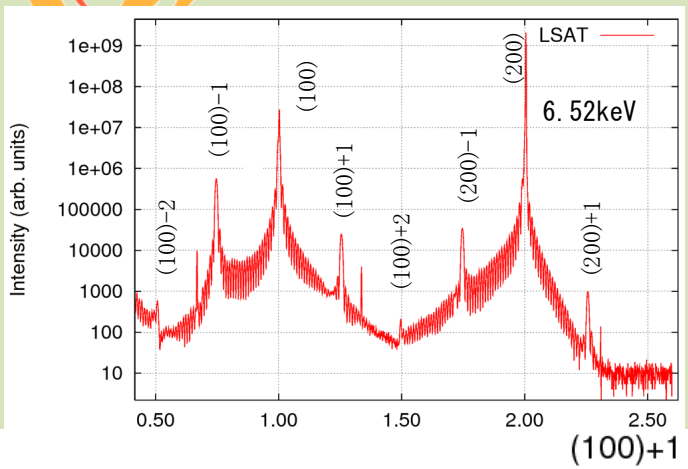


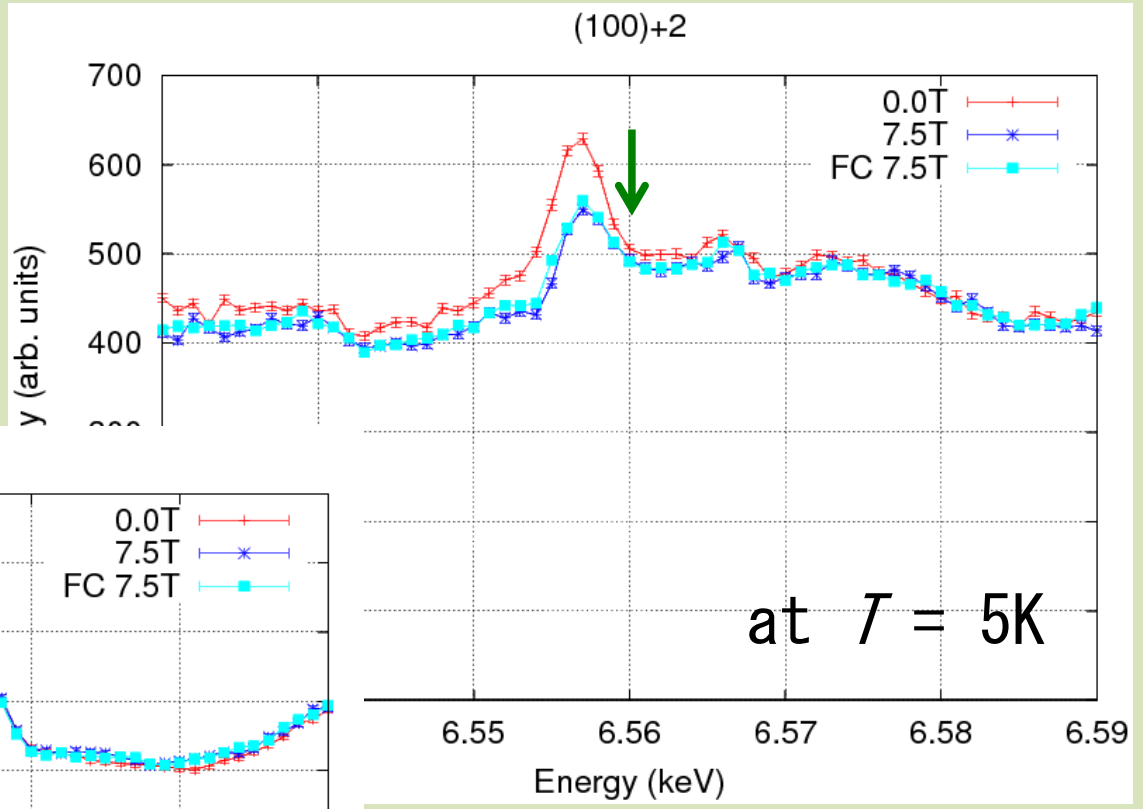
T = 5K vs. 300K

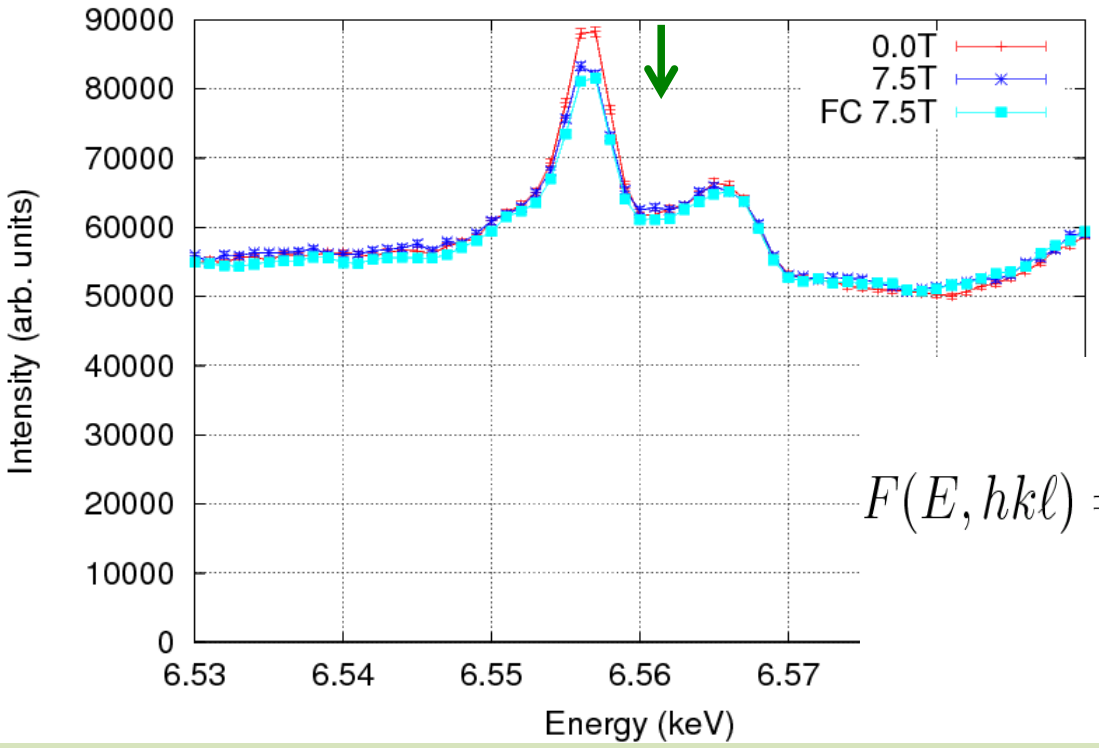
0 T vs. 7.5 T at T = 5K

Magnetic effect for Mn valence state

studied by resonant x-ray scattering







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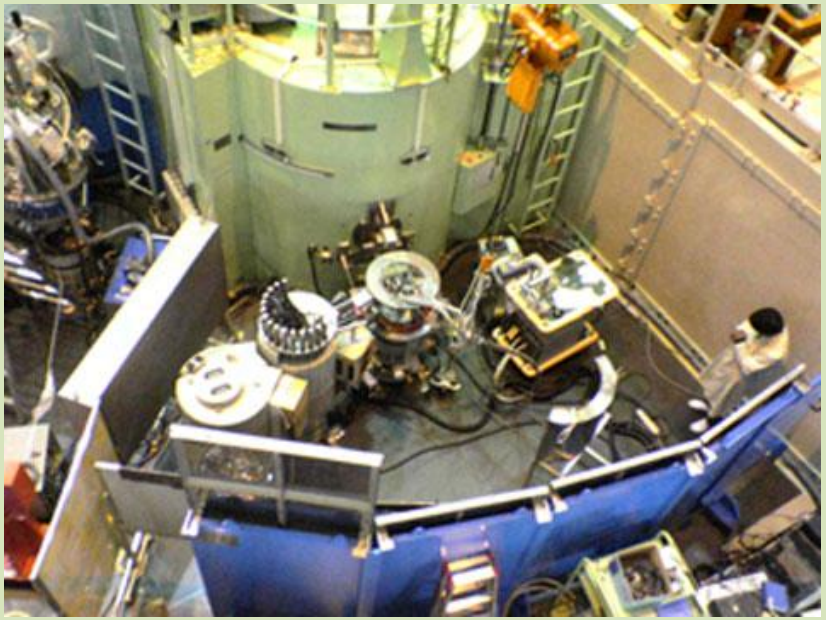
中性子磁気散乱による人工格子の磁性研究の可能性

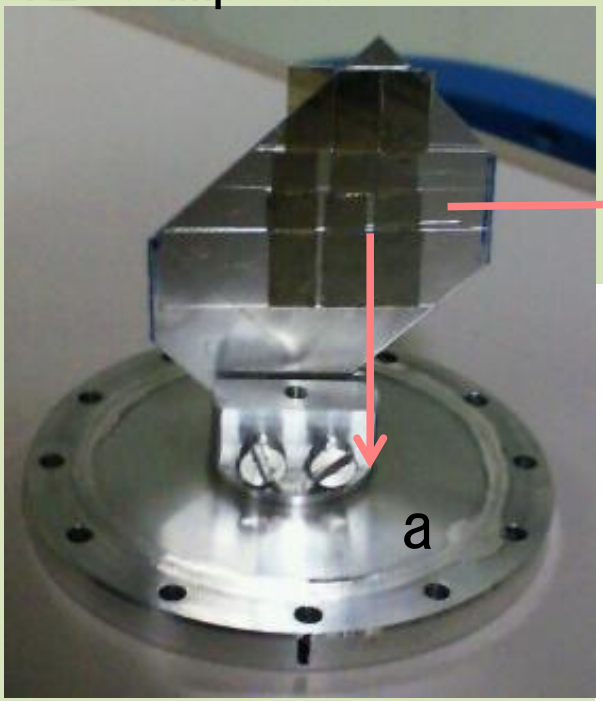


TOPAN(6G) at JRR-3 in Tokai

Tohoku Univ. : K. Iwasa

L2S2/LSAT

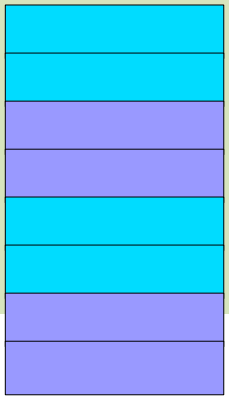
12 samples



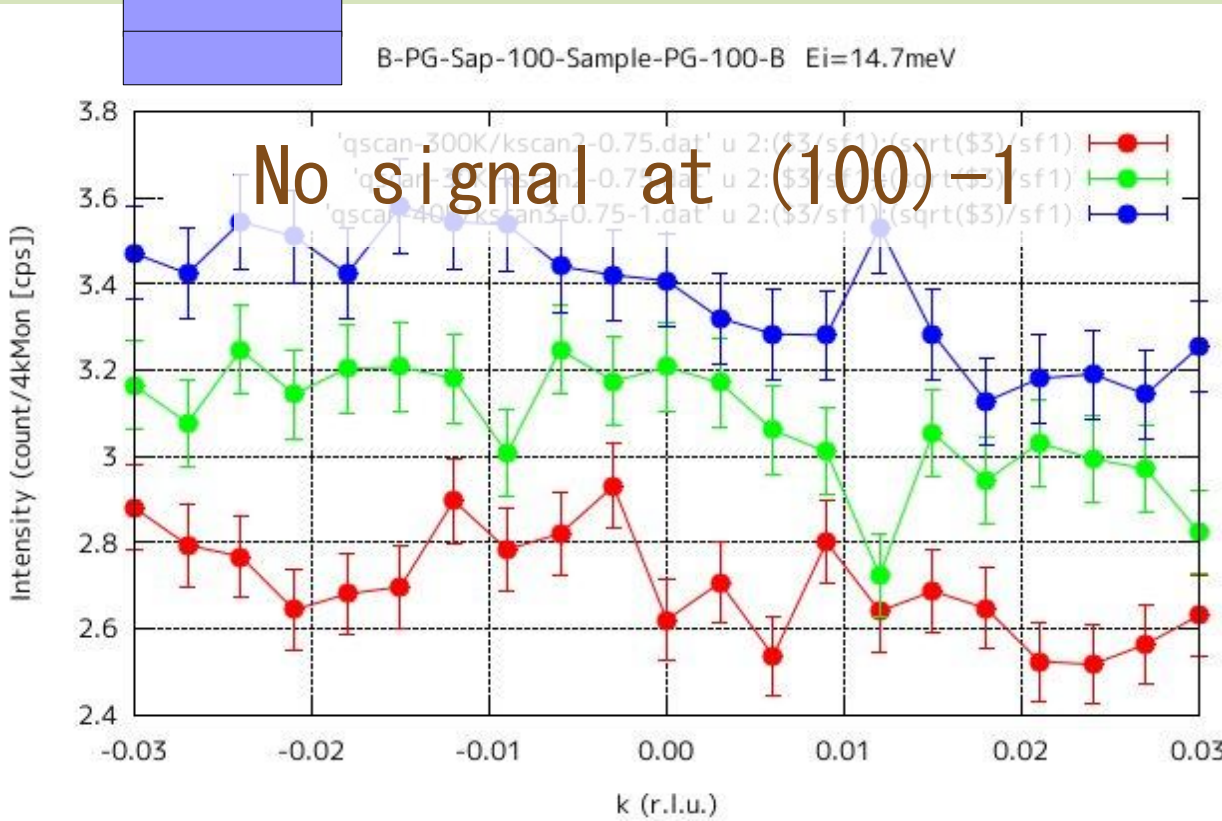
3cmx1.5cmx400Å

< 0.3x0.3x0.3mm^3

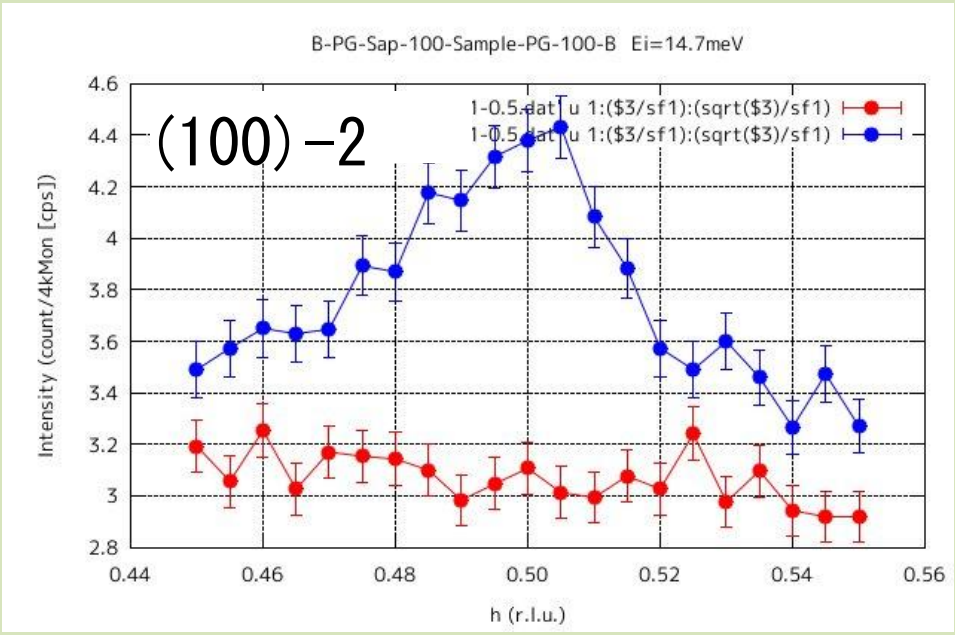
$(LaMnO_3)_2(SrMnO_3)_2$

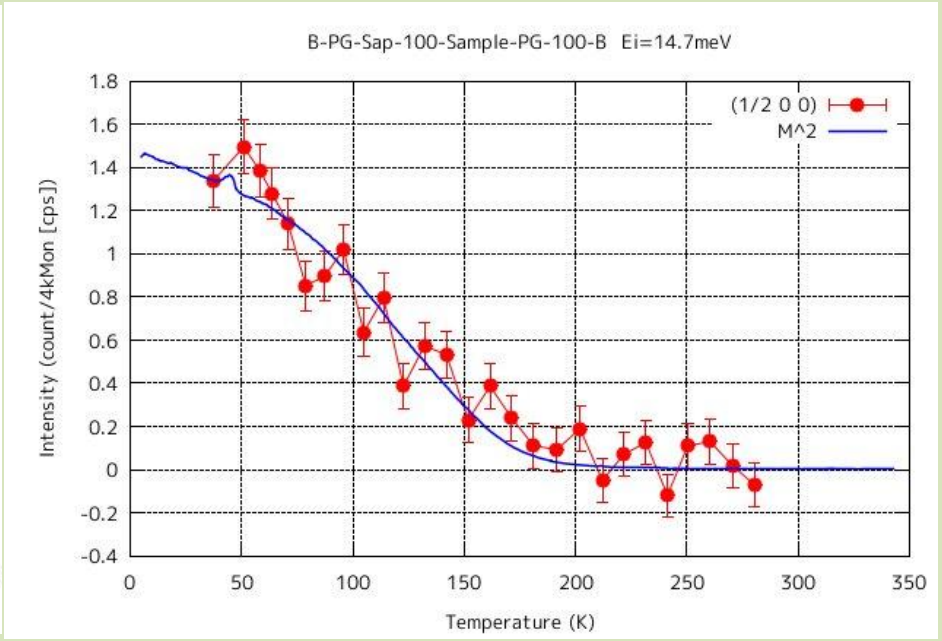


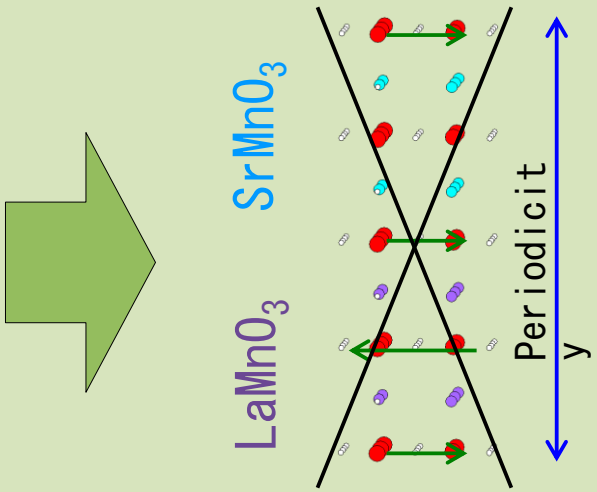
Magnetic scattering at (100)±1

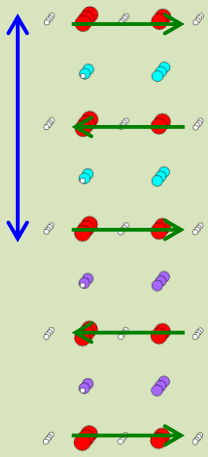


Magnetic scattering: L2S2/LSAT



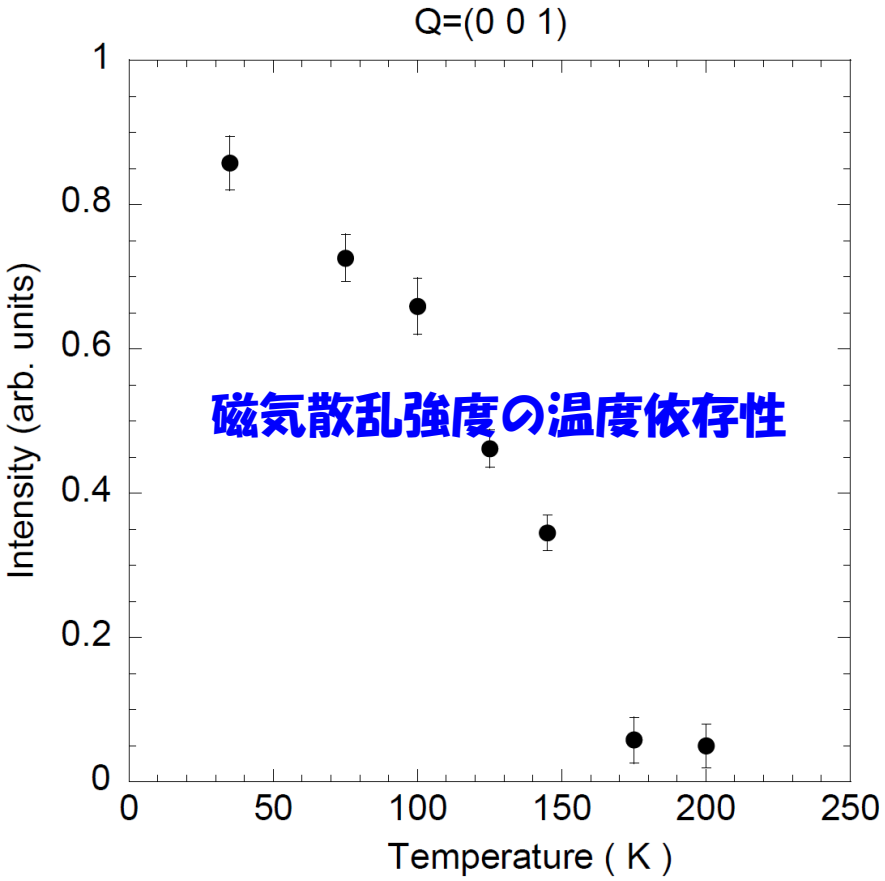


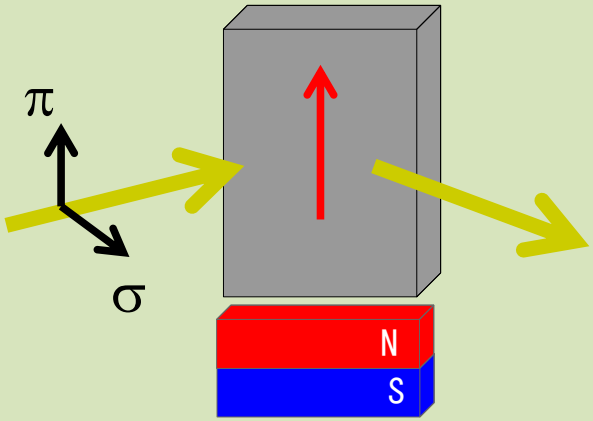


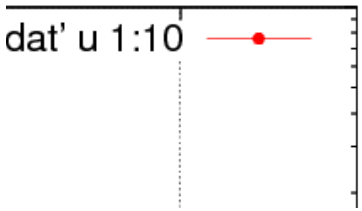


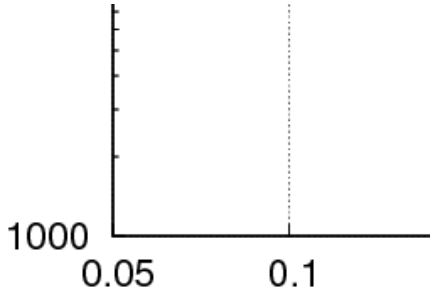
Simple AFM

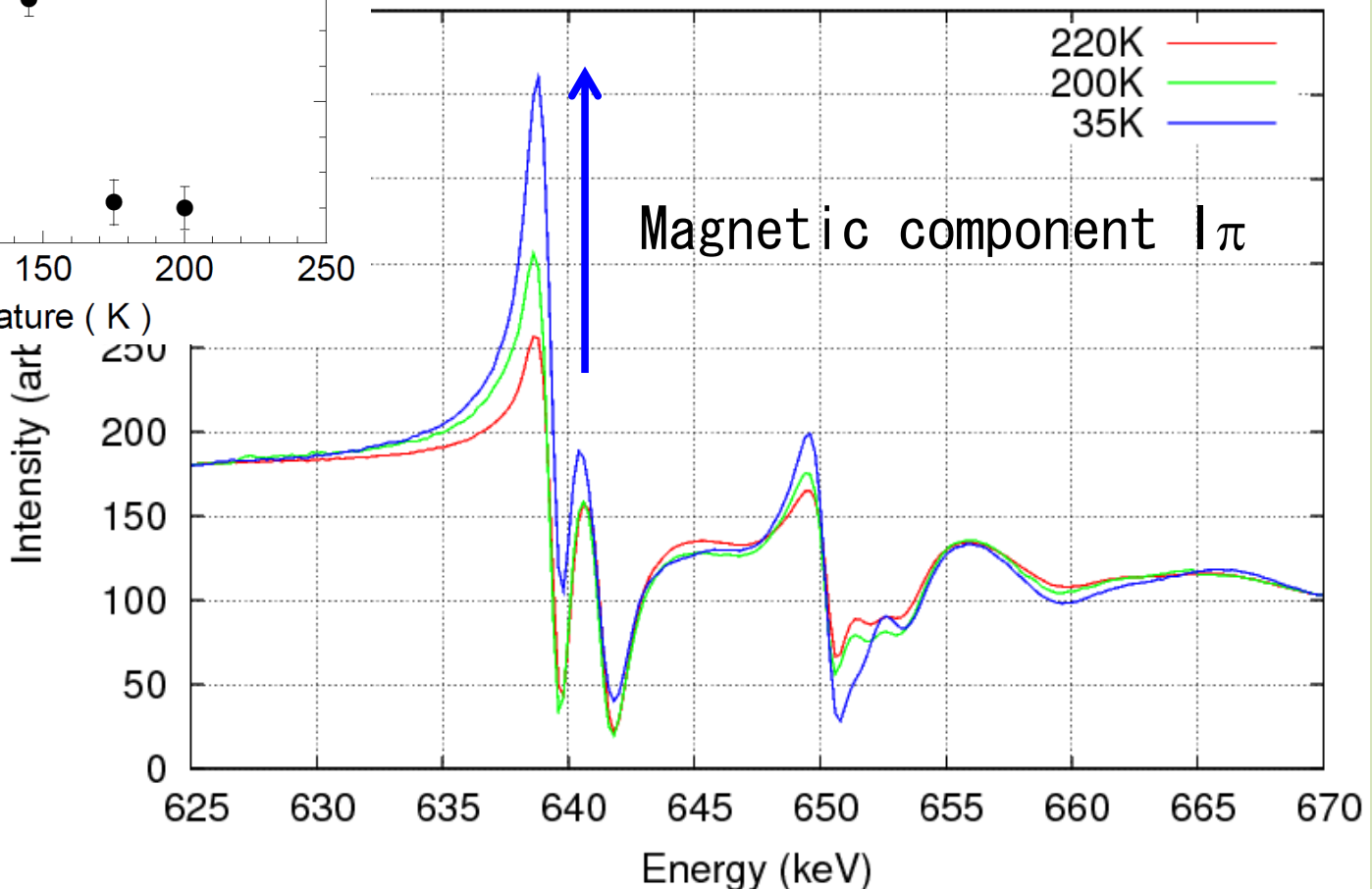
dge: L5S5











久保田
（JAEA）

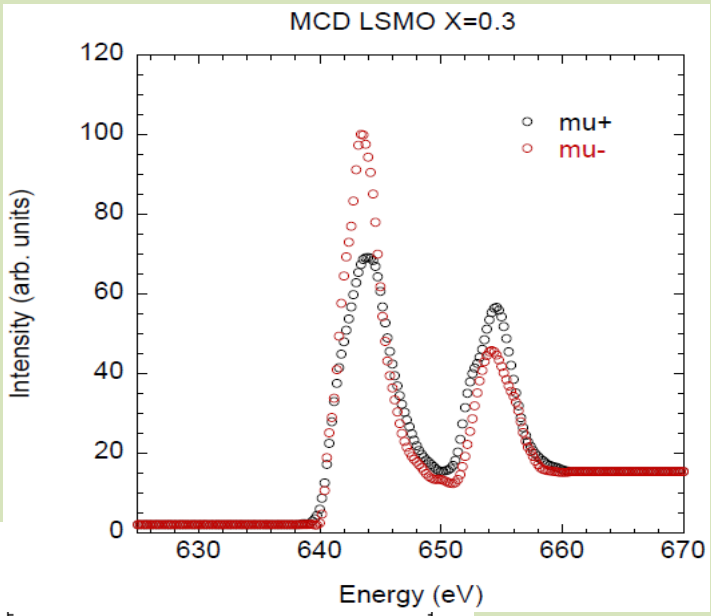
Form factor

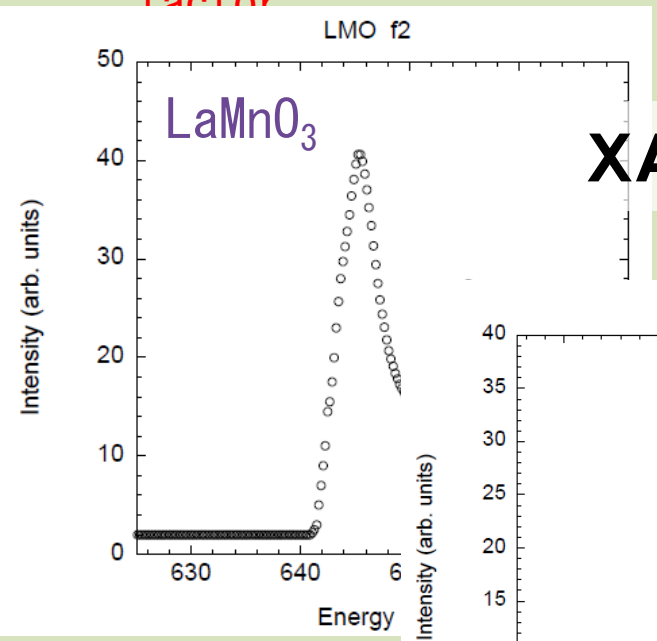
$$I(E, hk\ell) = |F(E, hk\ell)|^2$$

$$F(E, hk\ell) = \sum_i f_i(E) exp[-2\pi i(hx_i + ky_i + \ell z_i)]$$

$$f(E) = f_0 + f'(E) + if''(E)$$

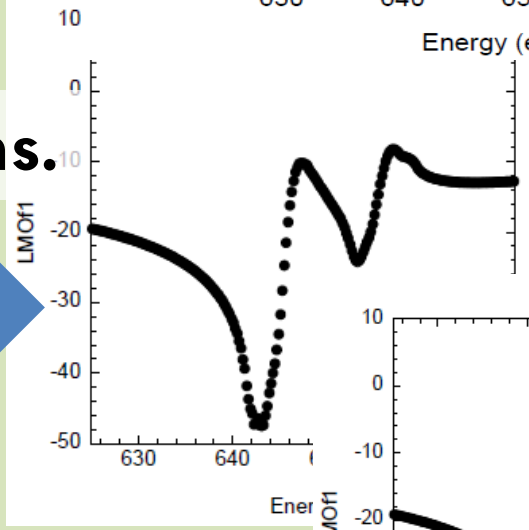
X-ray anomalous scattering factor

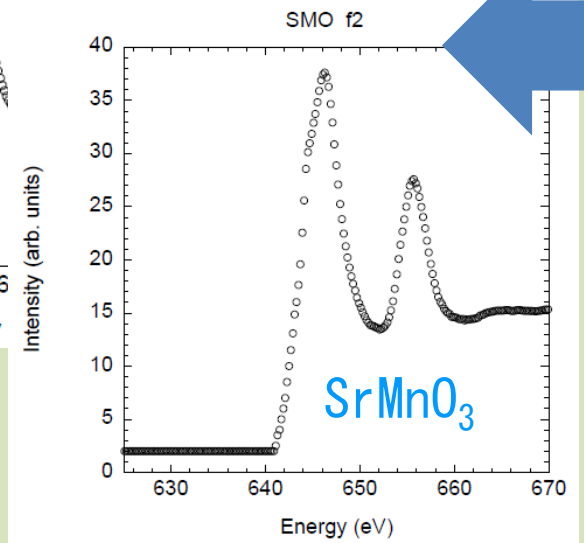


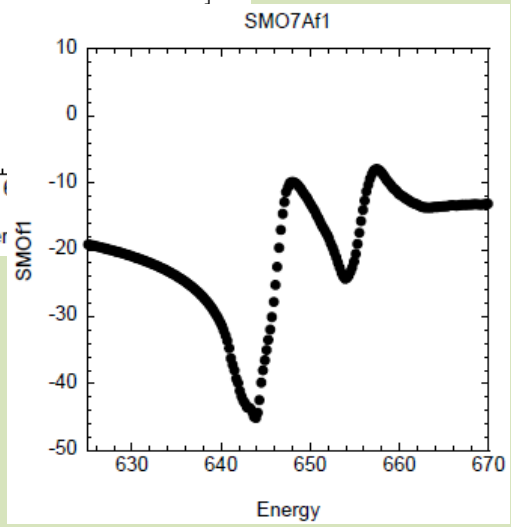


XAS

K-K trans.







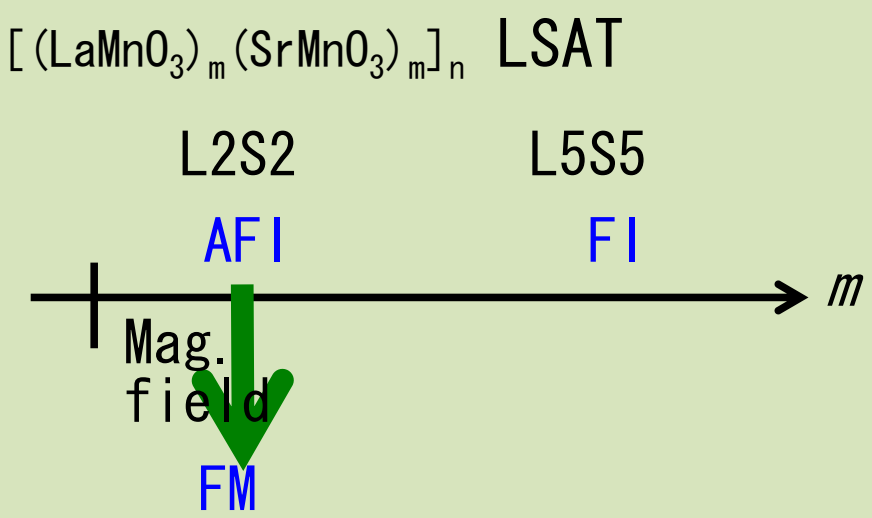
Study of artificial superlattice

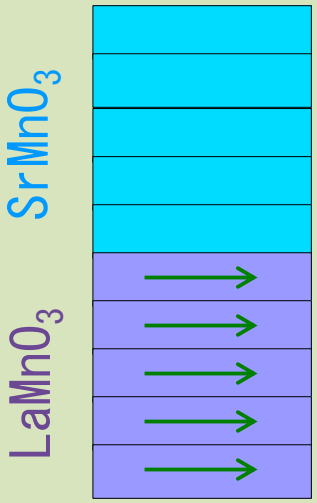
- Mn valence distribution
  Stacking structure (crystal structure)

  → Resonant and non-resonant x-ray scattering

- Magnetic structure

  → Neutron magnetic scattering / Reflectivity
  → Resonant magnetic x-ray scattering: Mn L-edge





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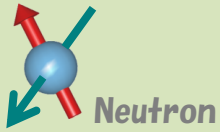

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