共鳴軟X線散乱研究への硬X線領域からのアプローチと研究展開

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

中尾裕則

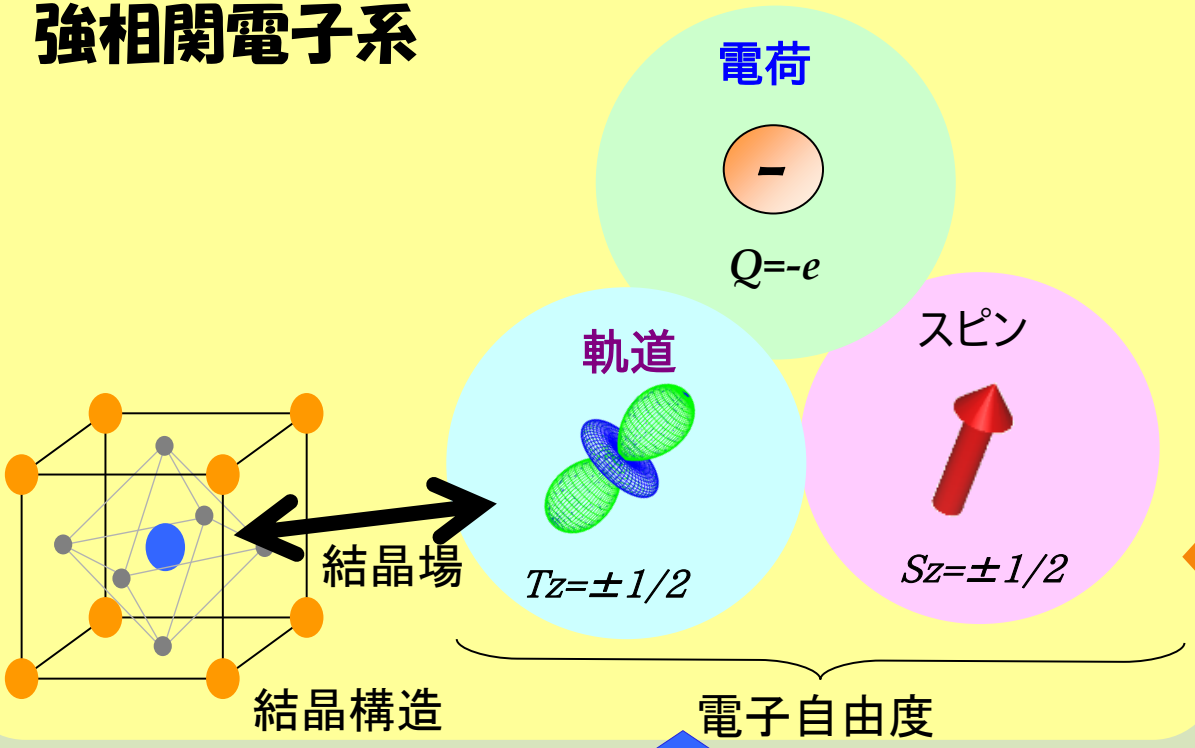
Outline

- Introduction
  硬X線領域でのRXSとその問題点

- Room Temperature Ferri-magnet: $Sr_3YCo_4O_{10.5}$
- Artificial superlattice: $[(LaMnO_3)_m(SrMnO_3)_m]_n$

構造物性研究

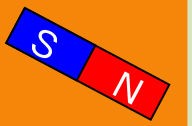
強相関電子系



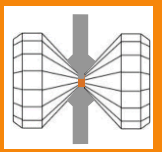
多様な物性の出現

高温超伝導、
巨大磁気抵抗効果、
巨大電気磁気効果、
重い電子系.....

外場応答



温度、圧力、磁場、
電場、光...



共鳴X線散乱 (回折＋分光)による、
軌道・**電荷**・**スピン**秩序状態の解明

共鳴X線散乱(RXS)

原子散乱因子

$$f = f_0(Q) + f''(E) + i\,f''(E)$$

異常分散項

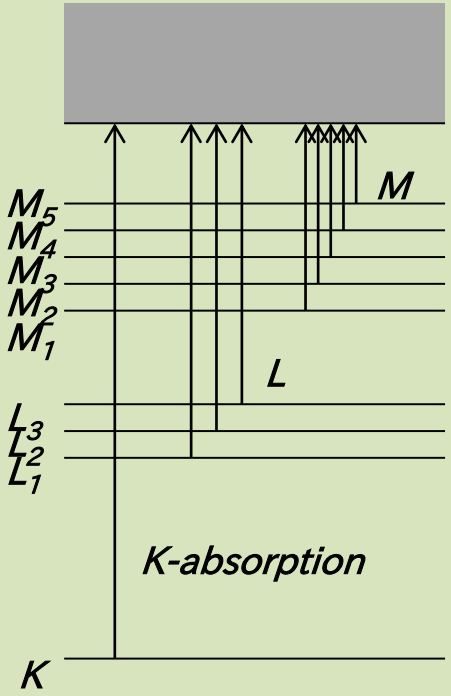
吸収端で顕著な変化

（原子種: / 軌道: *K*-, *L*-, *M*-… edge）の区別が可能

狙いの原子回りの局所情報

- 吸収端エネルギー - 電荷状態
- テンソル原子散乱因子 - 配位場
- スピン - 軌道状態 / 共有結合

X線回折 ⟶ 周期性

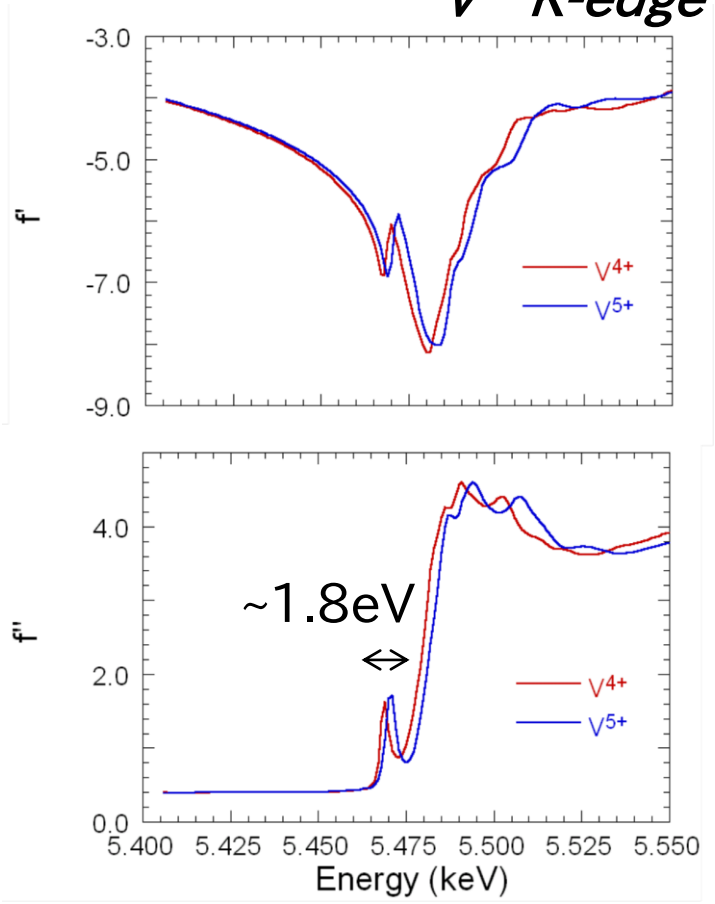


共鳴X線散乱(RXS)

原子散乱因子　$f = f_0(Q) + f'(E) + i\,f''(E)$

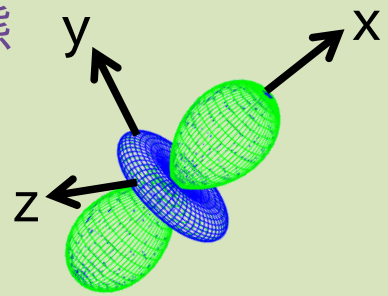
電荷状態　吸収端エネルギー

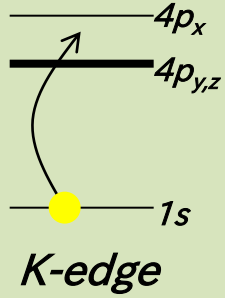
V　K-edge



Chemical shift

軌道状態





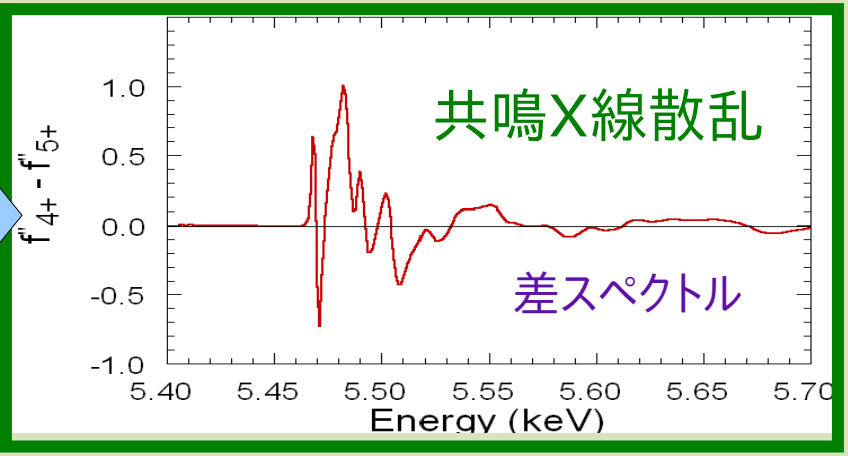
K-edge

テンソル原子散乱因子

$$f_a = \begin{pmatrix} f_{//} & 0 & 0 \\ 0 & f_{\perp} & 0 \\ 0 & 0 & f_{\perp} \end{pmatrix}$$

⇔ 偏光

LD



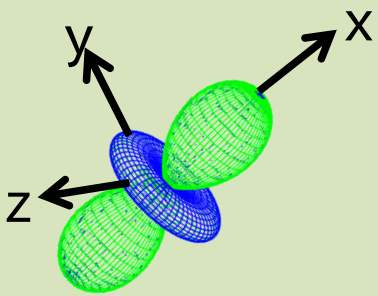
RXS technique

Atomic scattering factor

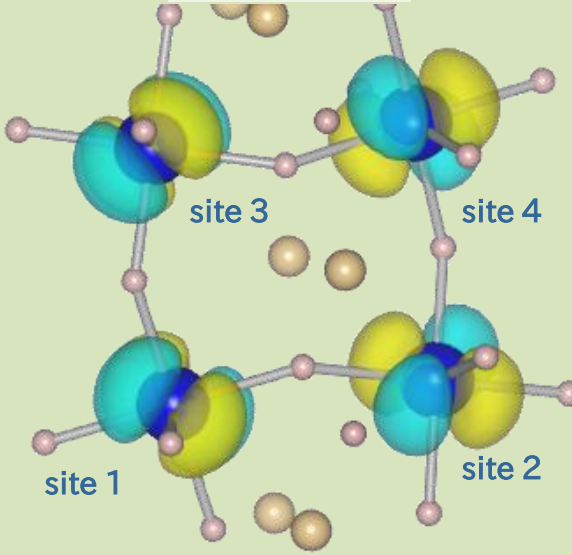
⟶ Tensor near the absorption energy

$$f = f_0(Q) + f' + i f''$$

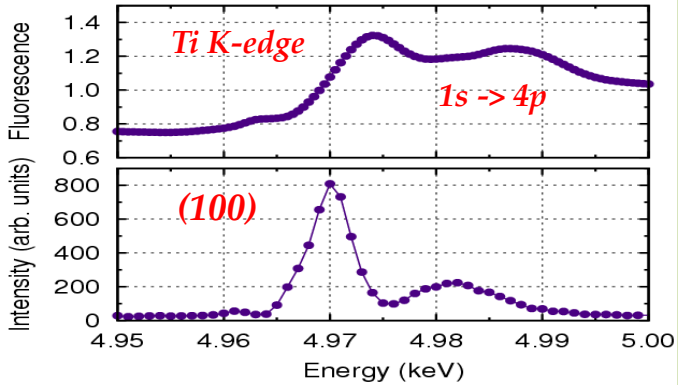
$$f_a = \begin{pmatrix} f_{//} & 0 & 0 \\ 0 & f_{\perp} & 0 \\ 0 & 0 & f_{\perp} \end{pmatrix}$$

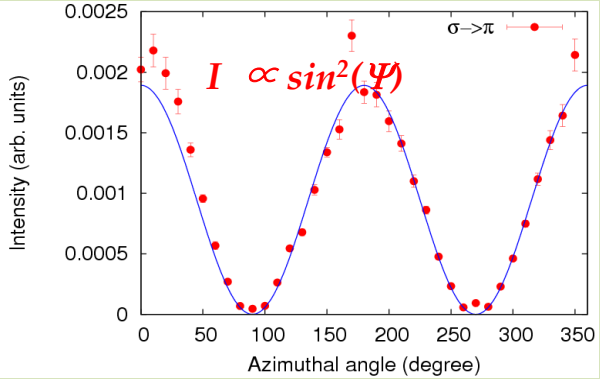


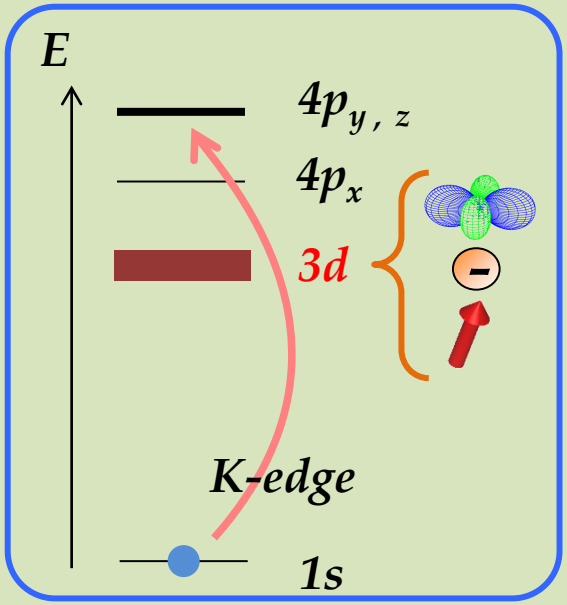
$YTiO_3$



1. Resonant phenomenon at absorption energy
2. Space group × (Observation of forbidden reflection)
3. Azimuthal angle, Polarization dependence







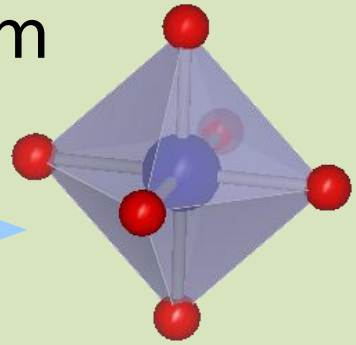
L-edgeでのRXS

H.N. et al., PRB **66** (2002) 184419.

H.N. et al., JPSJ **80** (2011) 023711.

Cobalt system: $Sr_3YCo_4O_{10.5}$

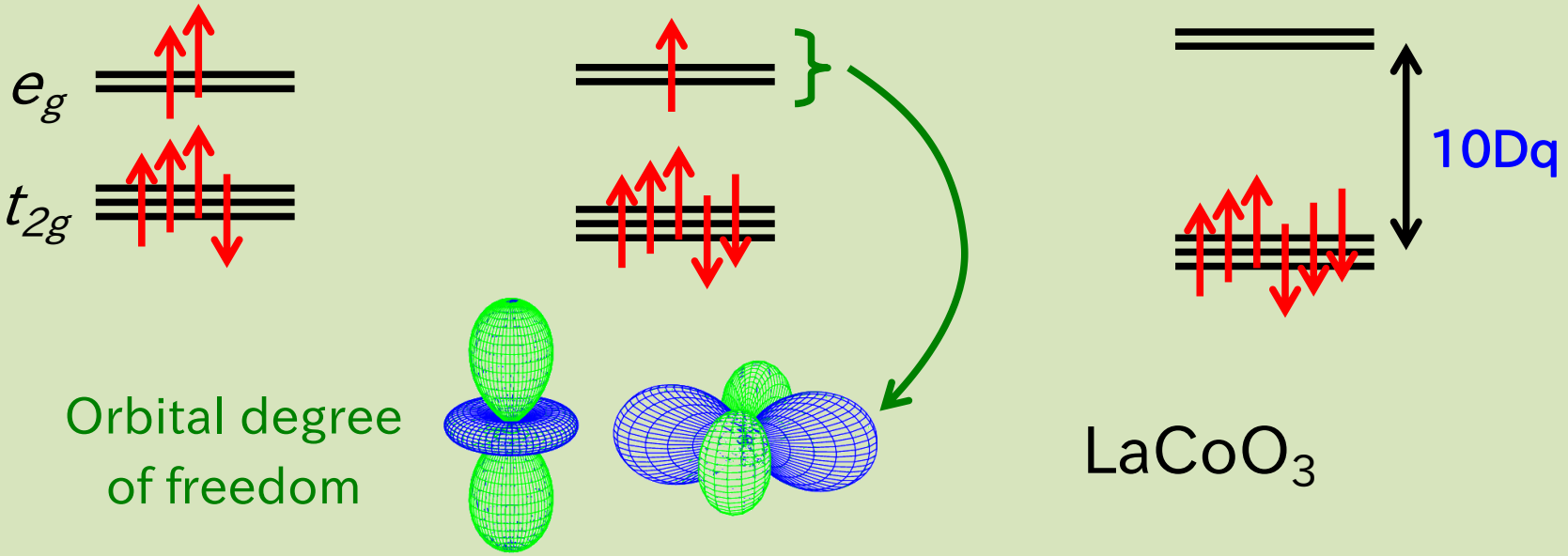
$Co^{3+}(3d^6)$: Spin State degree of freedom



Competition

Hund's coupling vs. CEF splitting

High Spin(HS) state | Intermediate Spin(IS) state | Low Spin(LS) state

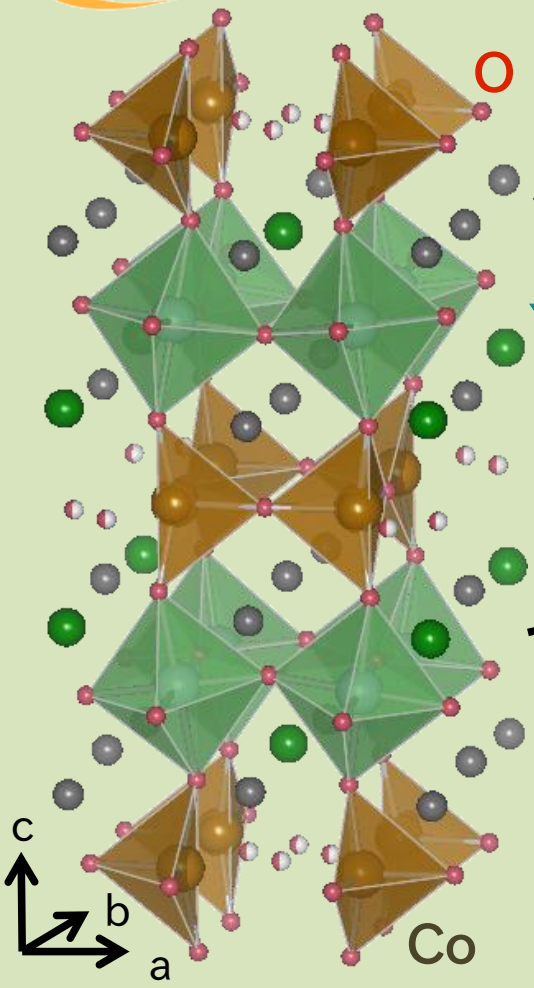


Orbital degree of freedom

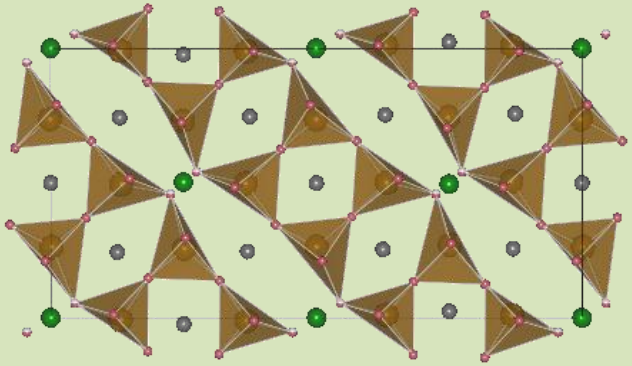
$LaCoO_3$

Room Temperature Ferri-magnet: $Sr_3YCo_4O_{10.5}$

Crystal Structure of $Sr_3YCo_4O_{10.5}$



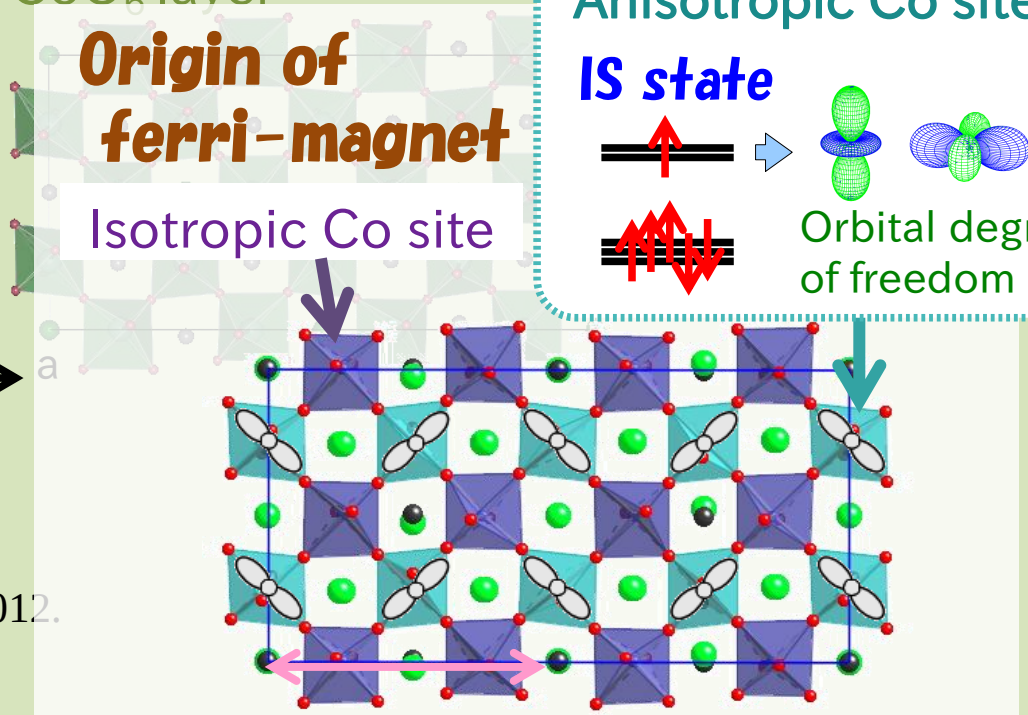
$CoO_{4.25}$ layer: oxygen vacancy



CoO_6 layer

Origin of ferri-magnet

Isotropic Co site



Anisotropic Co site

IS state

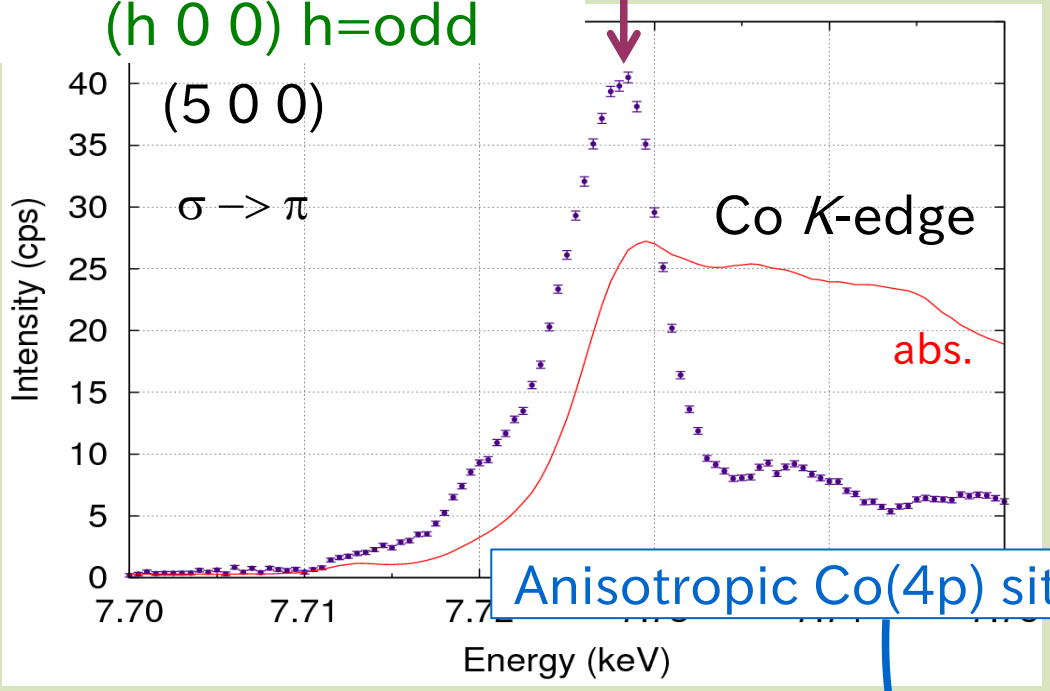
Orbital degree of freedom

Isotomin et al. : Chem. Mater. **15** (2003) 401.

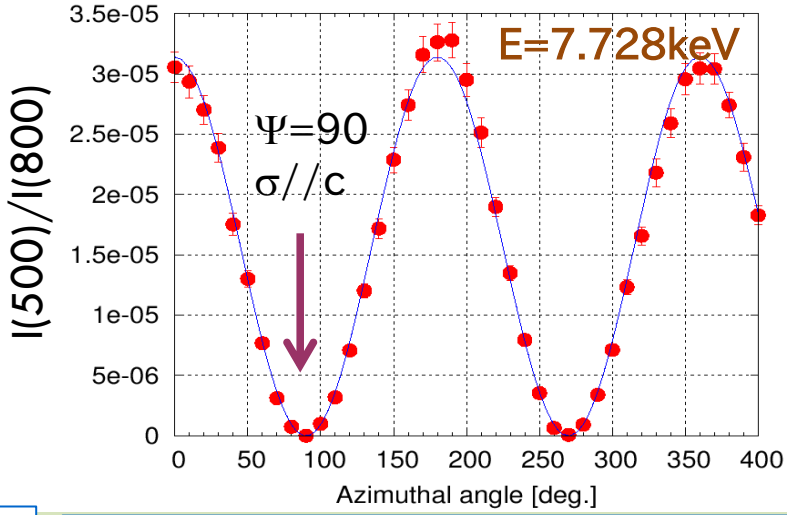
S. Ishiwata et al., PRB **75** (2007) 220406.

RXS reflecting anisotropy of Co sites

(h 0 0) h=odd



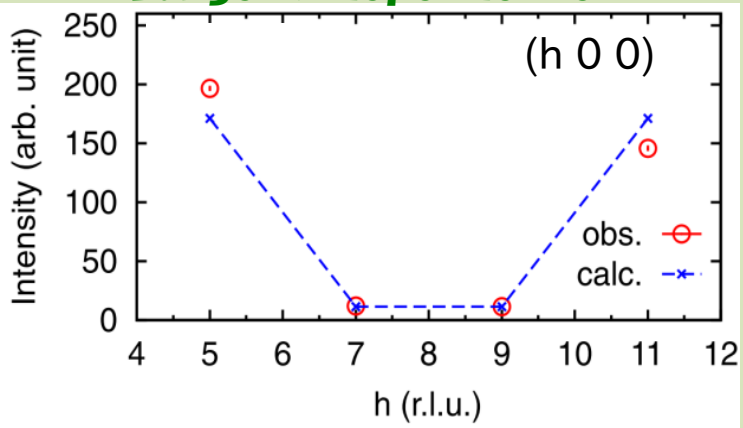
Azimuthal angle dependence



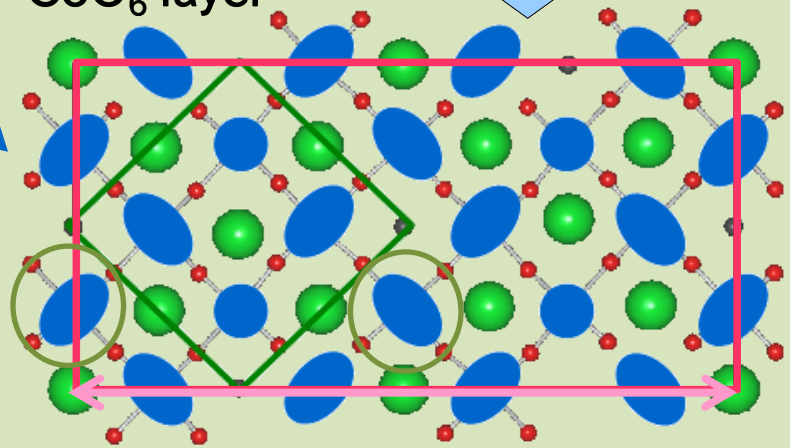
Anisotropic Co(4p) site

AF arrangement in *ab*-plane

Large Q-dependence

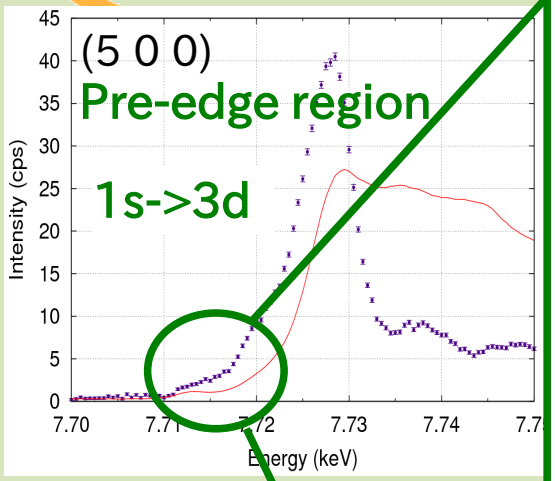


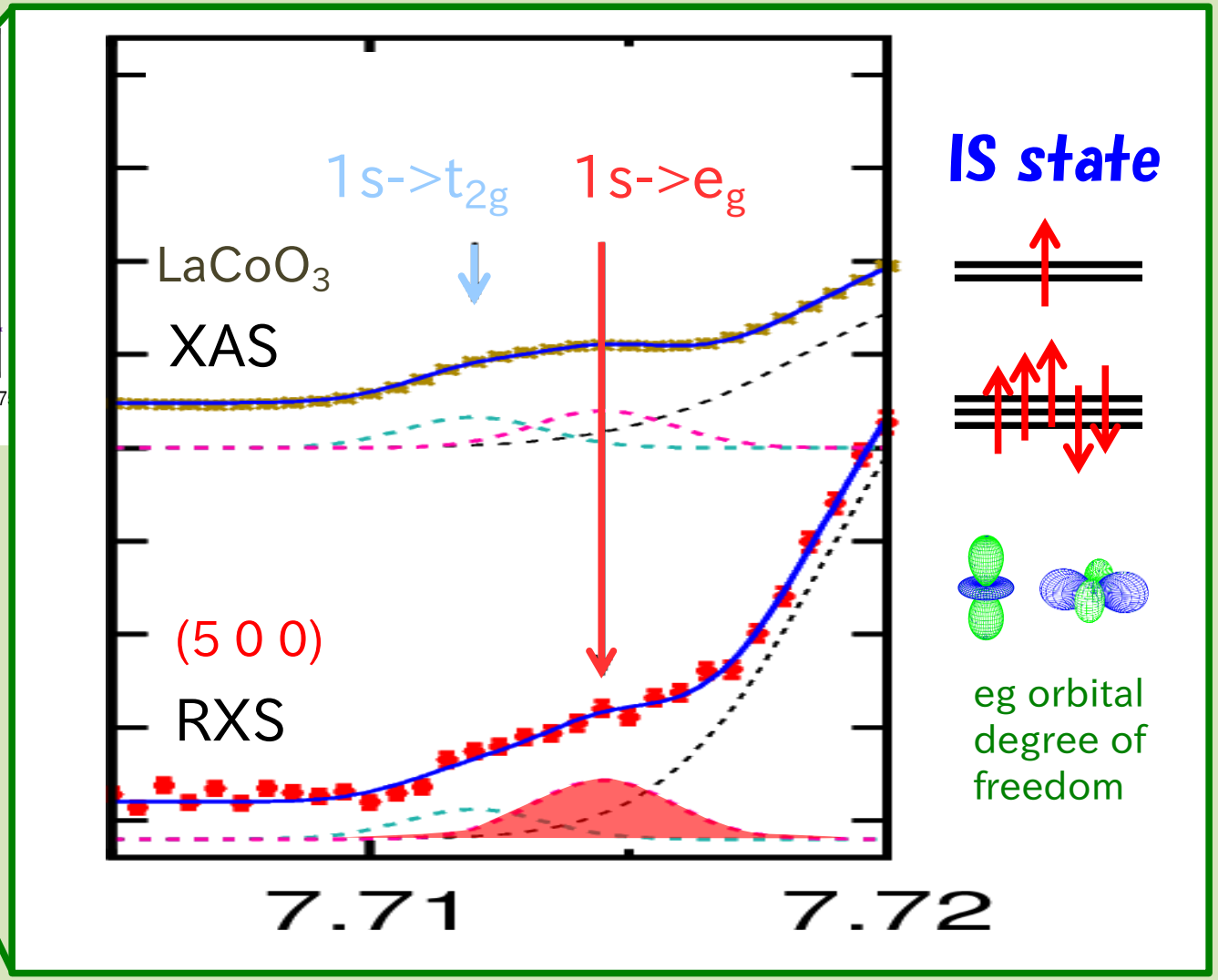
CoO_6 layer



RXS at pre-edge

Orbital ordering: e_g





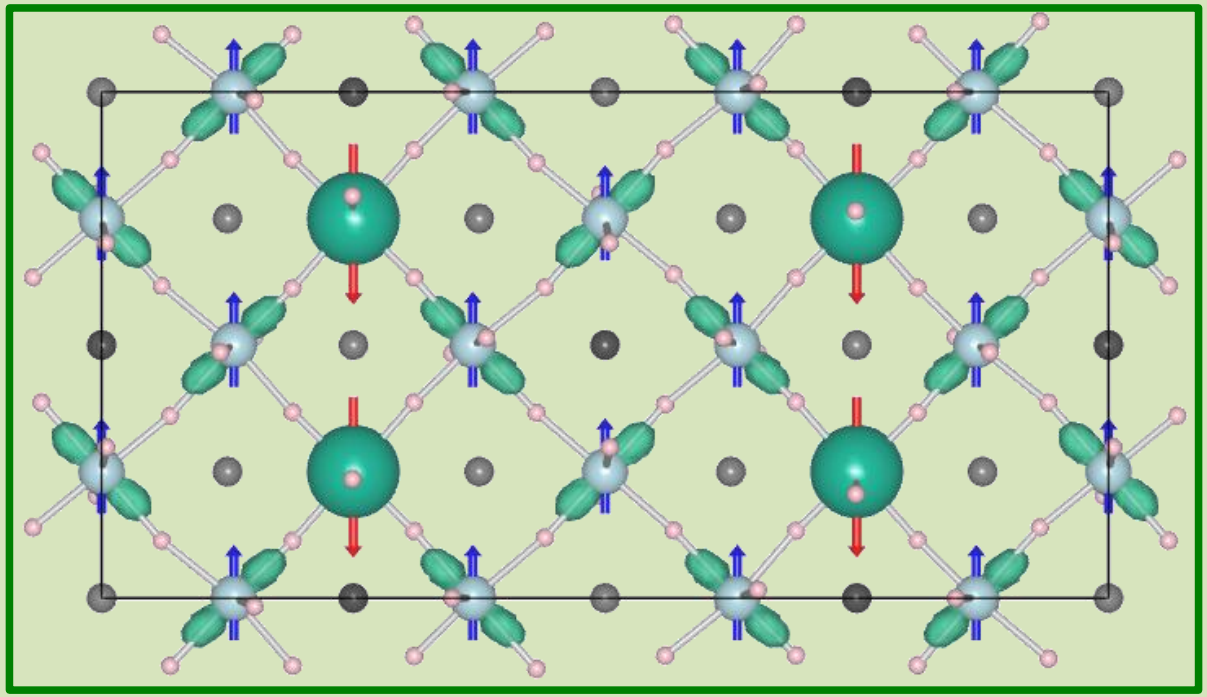
Existence of IS state

H.N. et al., JPSJ **80** (2011) 023711.

Summary: $Sr_3YCo_4O_{10.5}$

Origin of Ferri-magnet at RT in $Sr_3YCo_4O_{10.5}$

Co spin-state and AF- e_g-orbital ordering



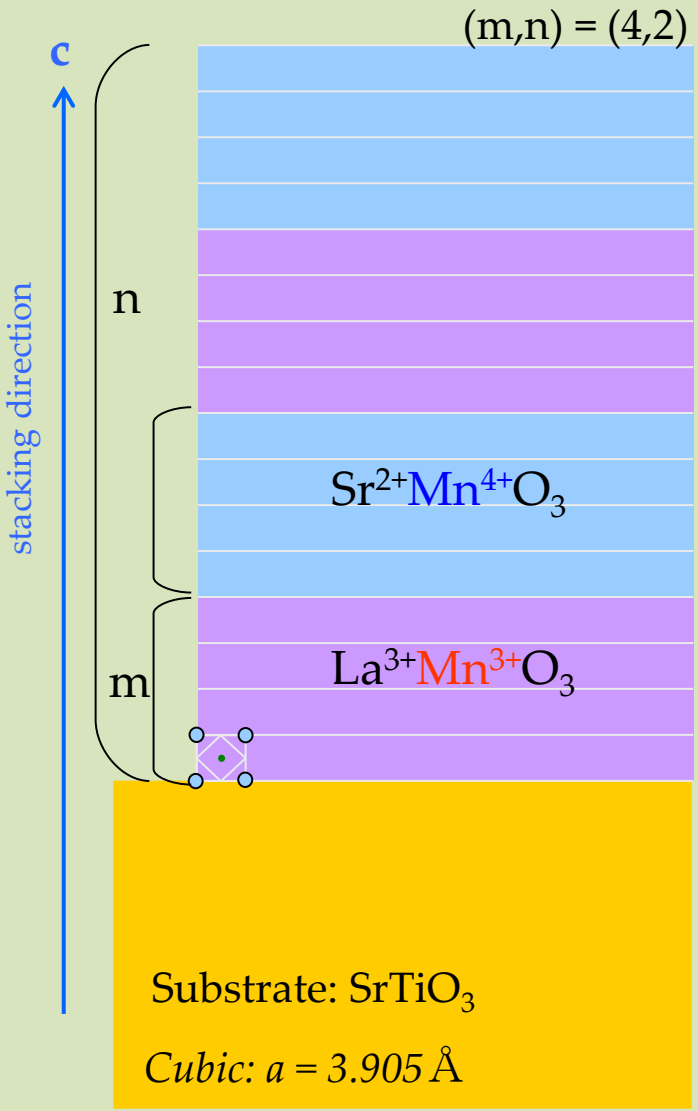
Ferri-magnetic structure

- *Resonant soft x-ray scattering*
- Neutron magnetic scattering

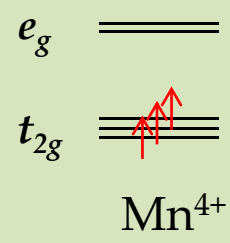
Artificial superlattice:

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

Perovskite structure

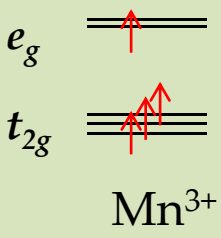


$Sr^{2+}Mn^{4+}O_3$ G-type AF



Band insulator

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

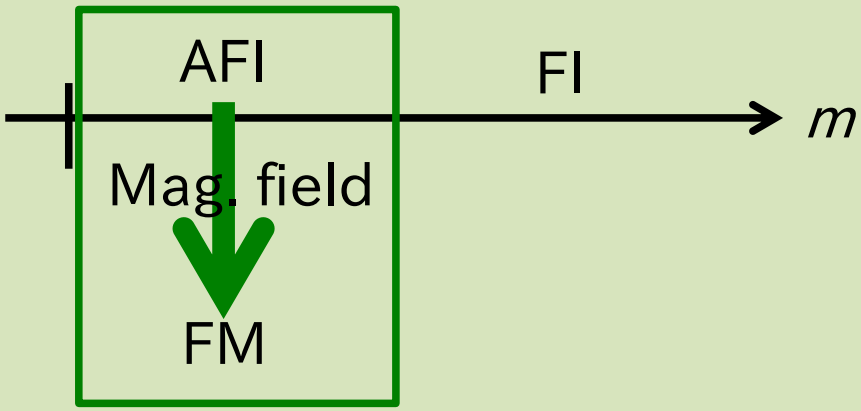


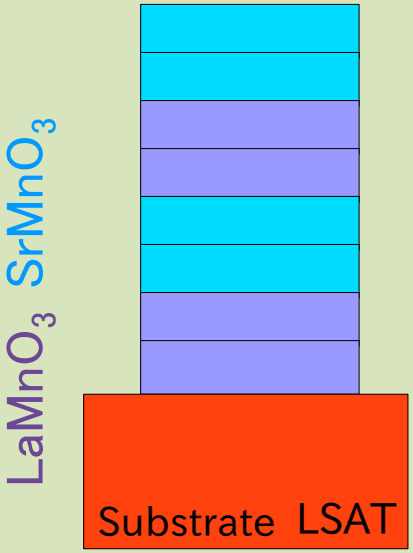
Mott insulator

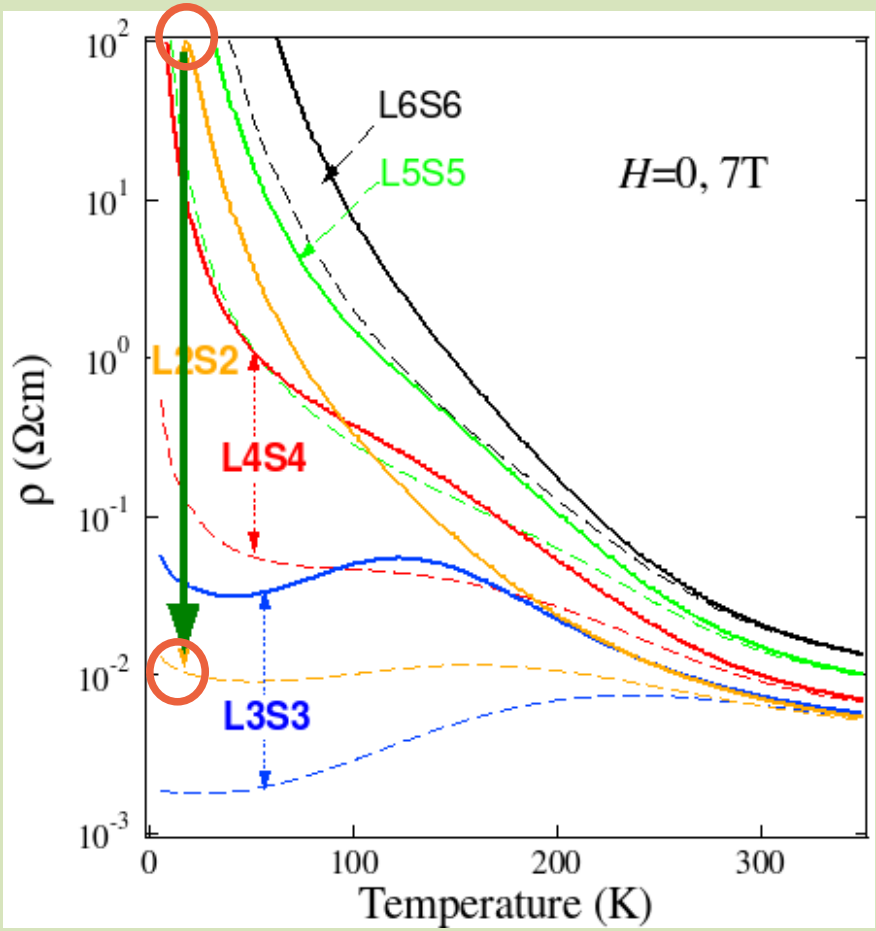
$[(LaMnO_3)_m(SrMnO_3)_m]_n$

産総研（山田,澤）

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



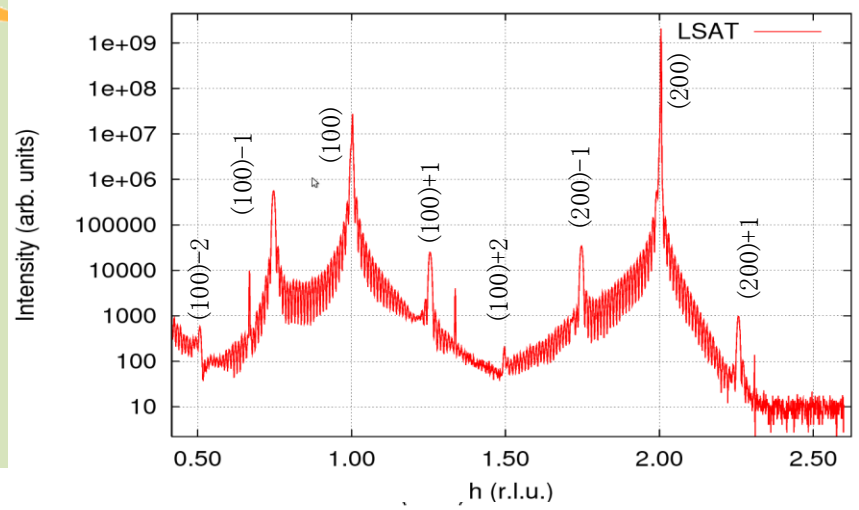




MR at the interface !?

H. Yamada *et al.*, PRB **81** (2010) 014410.

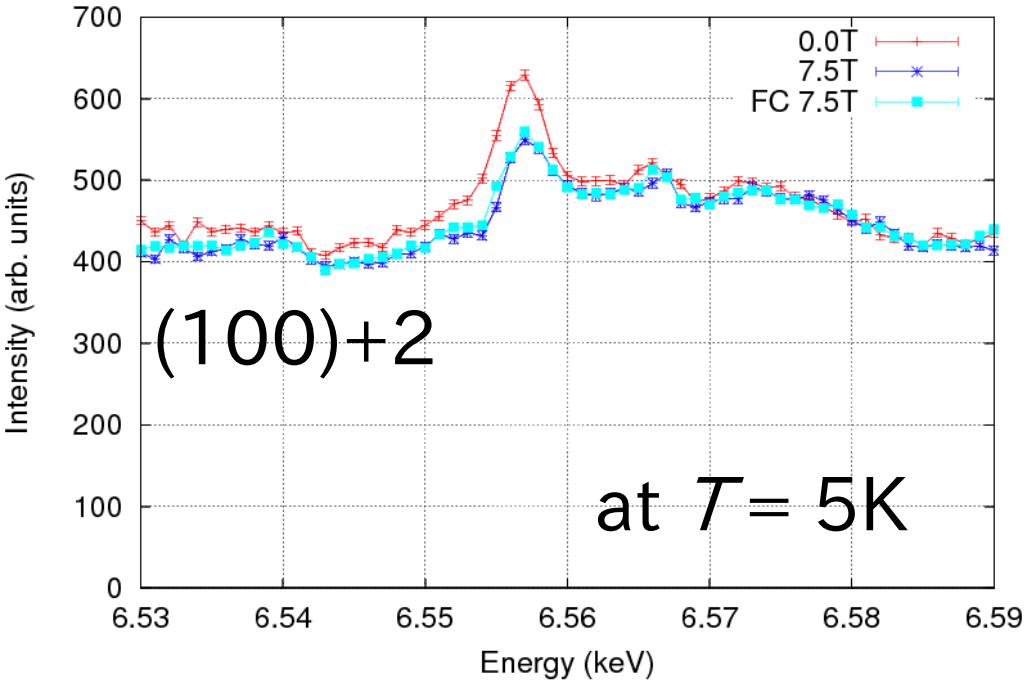
RXS: 電荷, 結晶構造

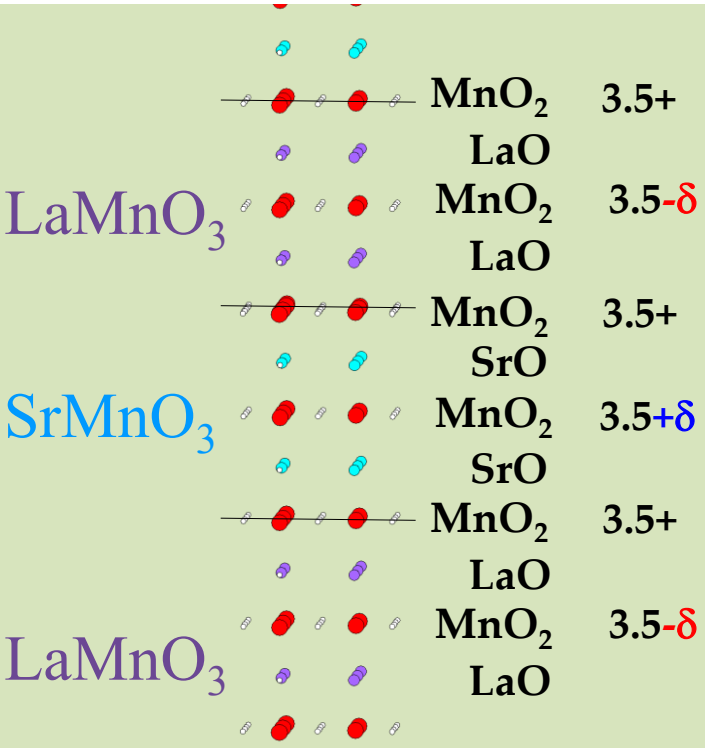


$$I(E,hk\ell) = |F(E,hk\ell)|^2$$

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

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





磁気構造？

Collaborator

J. Okamoto, Y. Yamasaki, T. Sudayama, Y. Murakami
Condensed Matter Research Center / Photon Factory, IMSS, KEK

Y. Yamaki, T. Murata	*Tohoku University*
W. Kobayashi	*Tsukuba University*
S. Ishiwata	*The University of Tokyo*
I. Terasaki	*Nagoya University*
M. Kubota	*Japan Atomic Energy Agency*
H. Yamada, A. Sawa	*Nanoelectronics Research Institute, AIST*