Magnetic and nematic orders of (111) 2DEGs

A. Paramekanti
(University of Toronto)

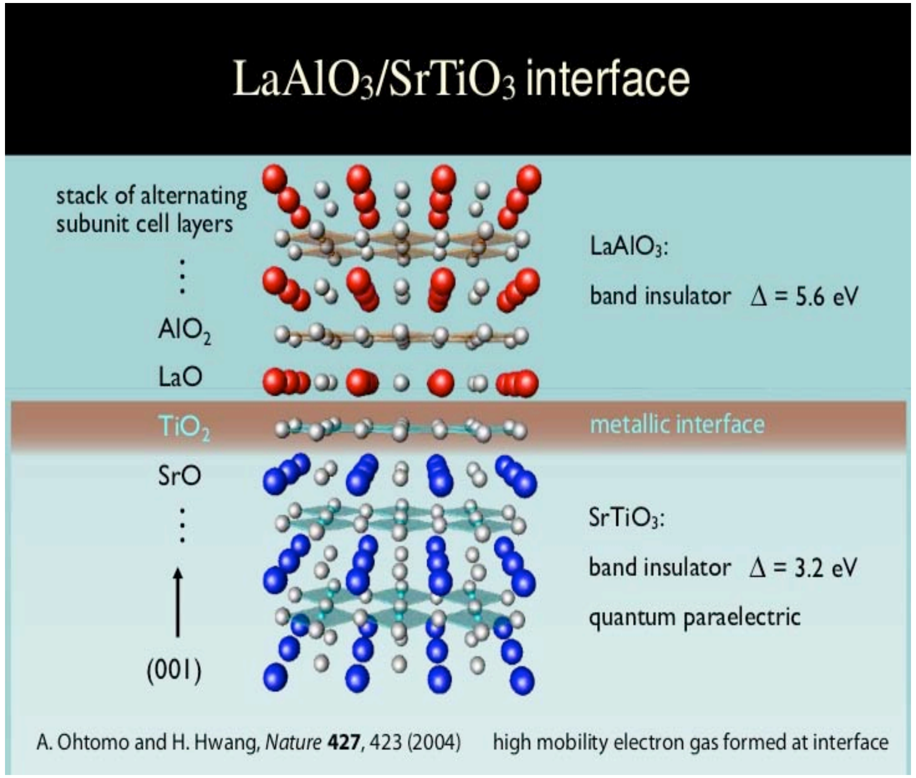
N. Boudjada, G. Wachtel, AP, arXiv:**1705.10795**

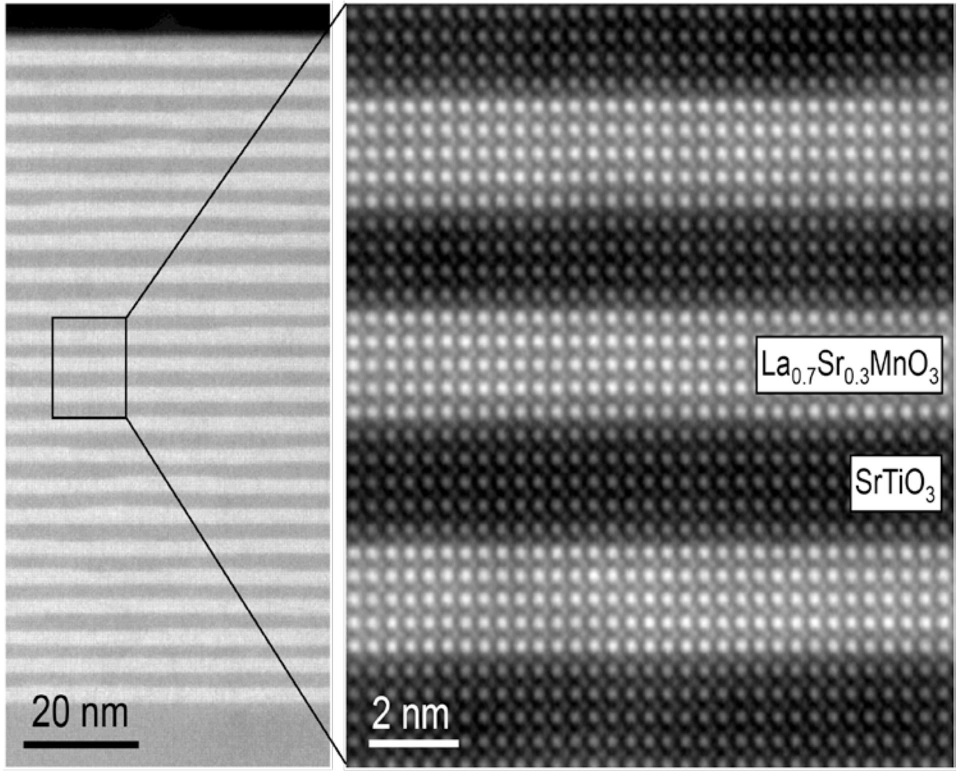
UNIVERSITY OF TORONTO

NSERC CRSNG

CIFAR CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Oxide heterostructures



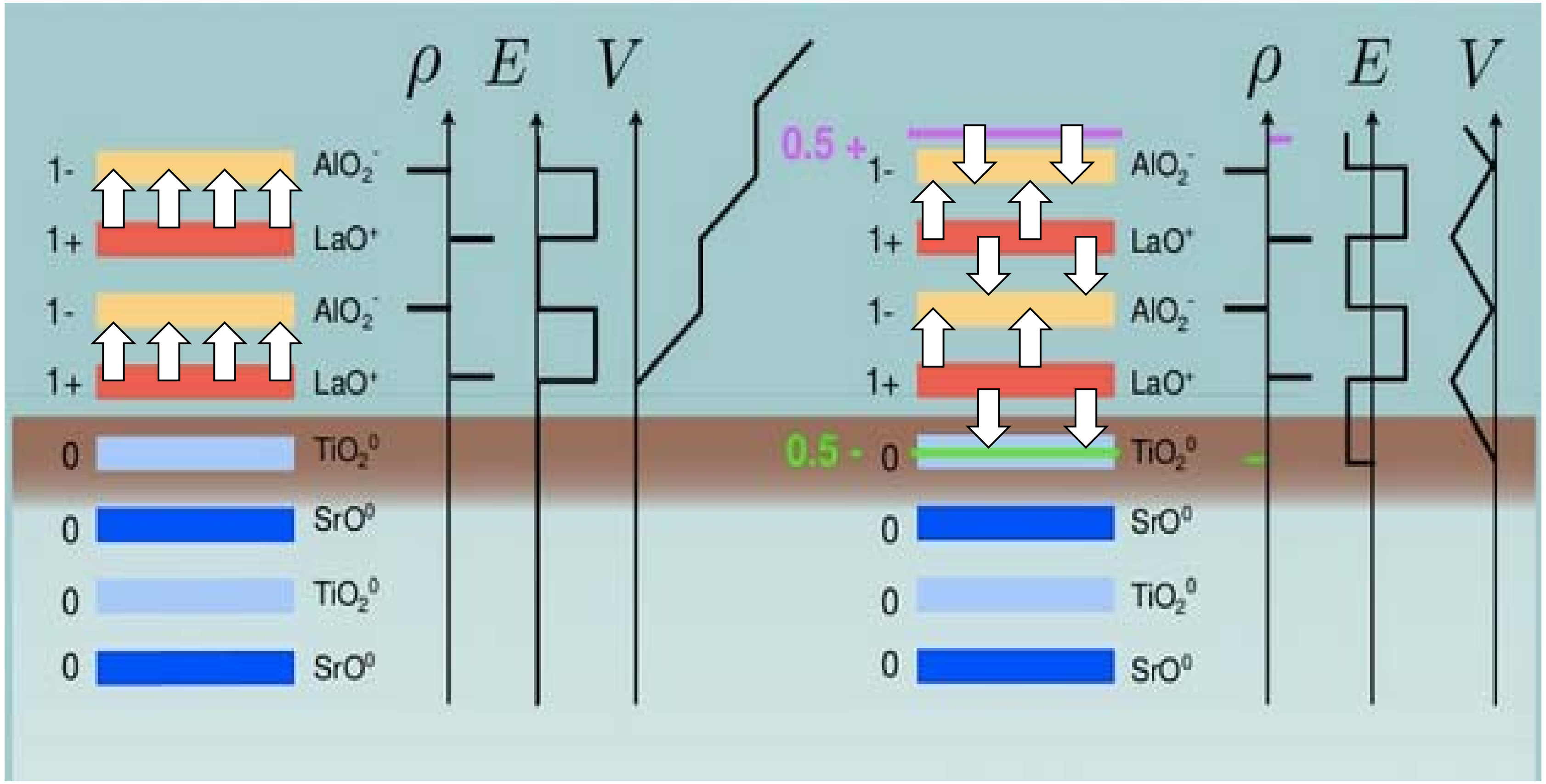


A. Ohmoto, H. Hwang, Nature (2004)

Ability to create atomically flat oxide layers
- Molecular beam epitaxy
- Pulsed laser deposition

Polar catastrophe

(001) $LaAlO_3$-$SrTiO_3$

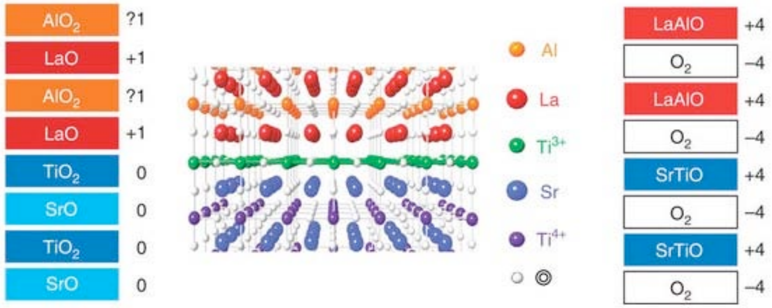


Nakagawa, Hwang, Muller, Nature (2006)

LaAlO3/SrTiO3 interface along [100]

H. Y. Hwang, J.M. Triscone, J. Mannhart,
R. Ashoori, K. A. Moler, ...

Expts: Magnetism + superconductivity



3d-3d Superlattices along [111]

nature materials LETTERS
PUBLISHED ONLINE: 22 JANUARY 2012 | DOI: 10.1038/NMAT3224

Exchange bias in $LaNiO_3$-$LaMnO_3$ superlattices

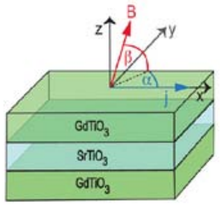
Marta Gibert[1]*, Pavlo Zubko[1], Raoul Scherwitzl[1], Jorge Íñiguez[2] and Jean-Marc Triscone[1]

AIP Applied Physics Letters

Local electronic and magnetic studies of an artificial La 2 FeCrO 6 double perovskite

Benjamin Gray, Ho Nyung Lee, Jian Liu, J. Chakhalian, and J. W. Freeland

Citation: Applied Physics Letters **97**, 013105 (2010); doi: 10.1063/1.3455323



Quantum Wells, Modulation Doping

S. Stemmer group (UCSB)

Magnetism, Mott transitions, Non-Fermi Liquid

3d/5d Superlattices along [111]

H. Takagi group (APL 2015)

ARTICLE
Received 20 Jun 2011 | Accepted 18 Nov 2011 | Published 20 Dec 2011
DOI: 10.1038/ncomms1602

Interface engineering of quantum Hall effects in digital transition metal oxide heterostructures

Di Xiao[1], Wenguang Zhu[1,2], Ying Ran[3], Naoto Nagaosa[4,5] & Satoshi Okamoto[1]

Rapid Communication

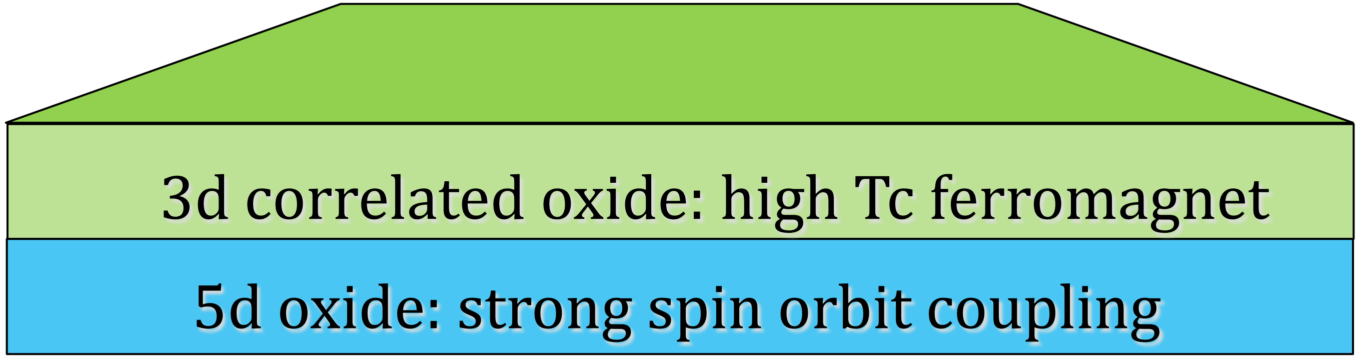
Topological insulators from complex orbital order in transition-metal oxides heterostructures

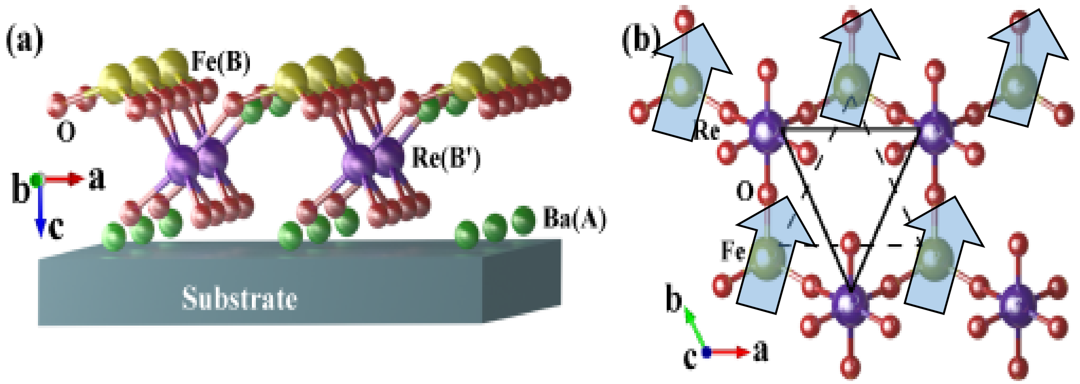
Andreas Rüegg and Gregory A. Fiete

Phys. Rev. B **84**, 201103(R) – Published 14 November 2011

Prediction of topological phases in simple TMO bilayers

Realizing high Tc quantum anomalous Hall effect





Fe layer: Magnetism
Re layer: SOC

DFT + Effective model

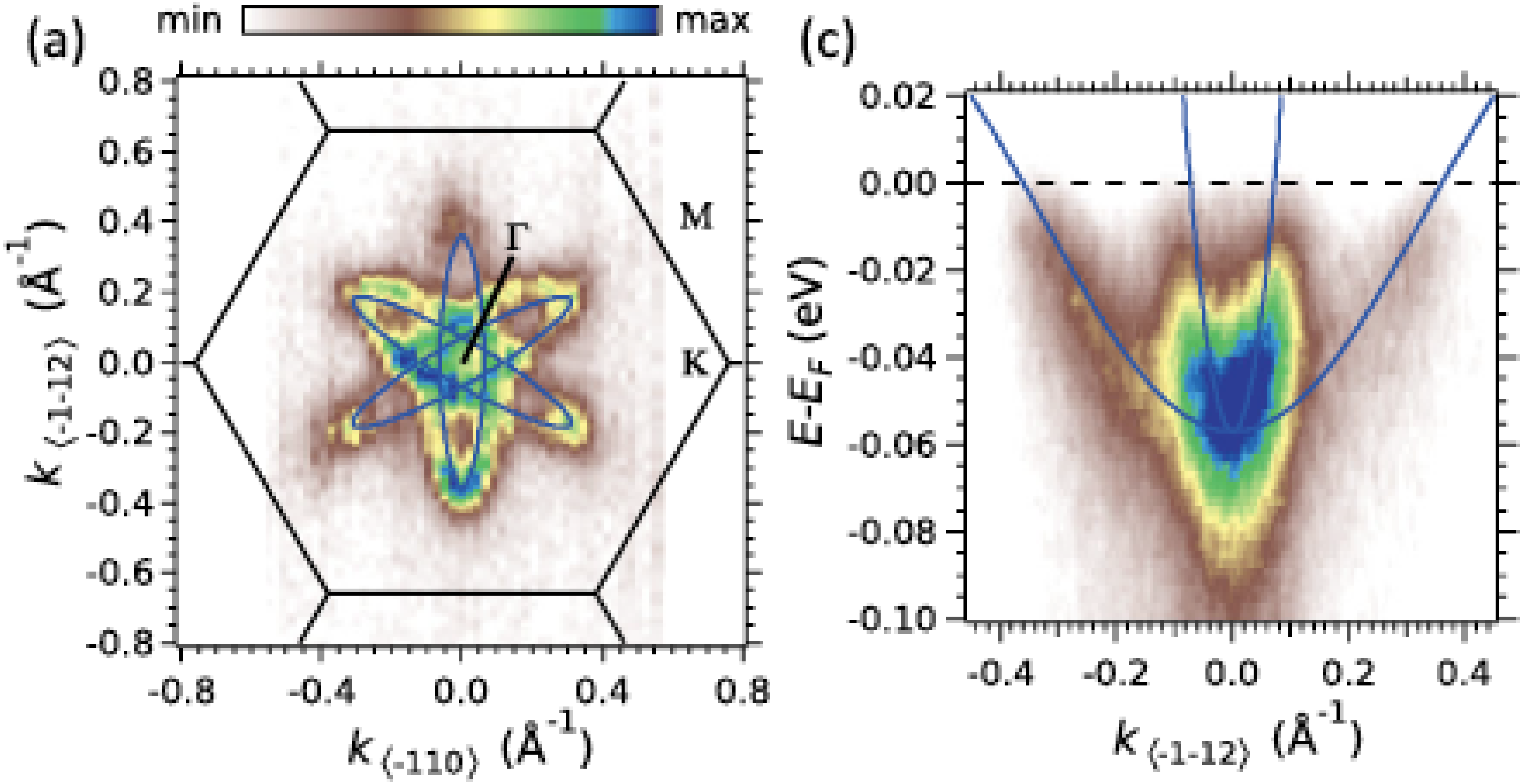
QAH gap ~ 100 meV
Ferromagnetic Tc ~ 300 K

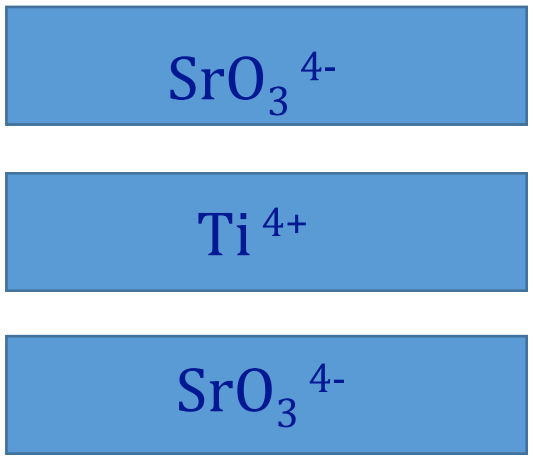
A.M. Cook, **AP** (***PRL*** 2014);
S. Baidya, U.Waghmare, **AP**,T.Saha-Dasgupta (PRB,2015+16)

$SrTiO_3$ (111) surface 2DEG

ARPES

Baumberger group, Geneva: S. McKeown Walker, et al, (PRL 2014)
Santander-Syro group: T. C. Rodel, et al, Phys. Rev. App. (2014)



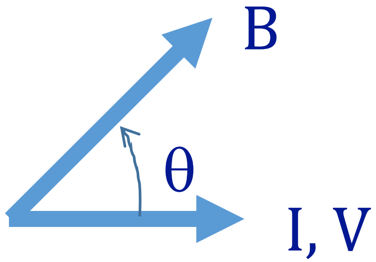


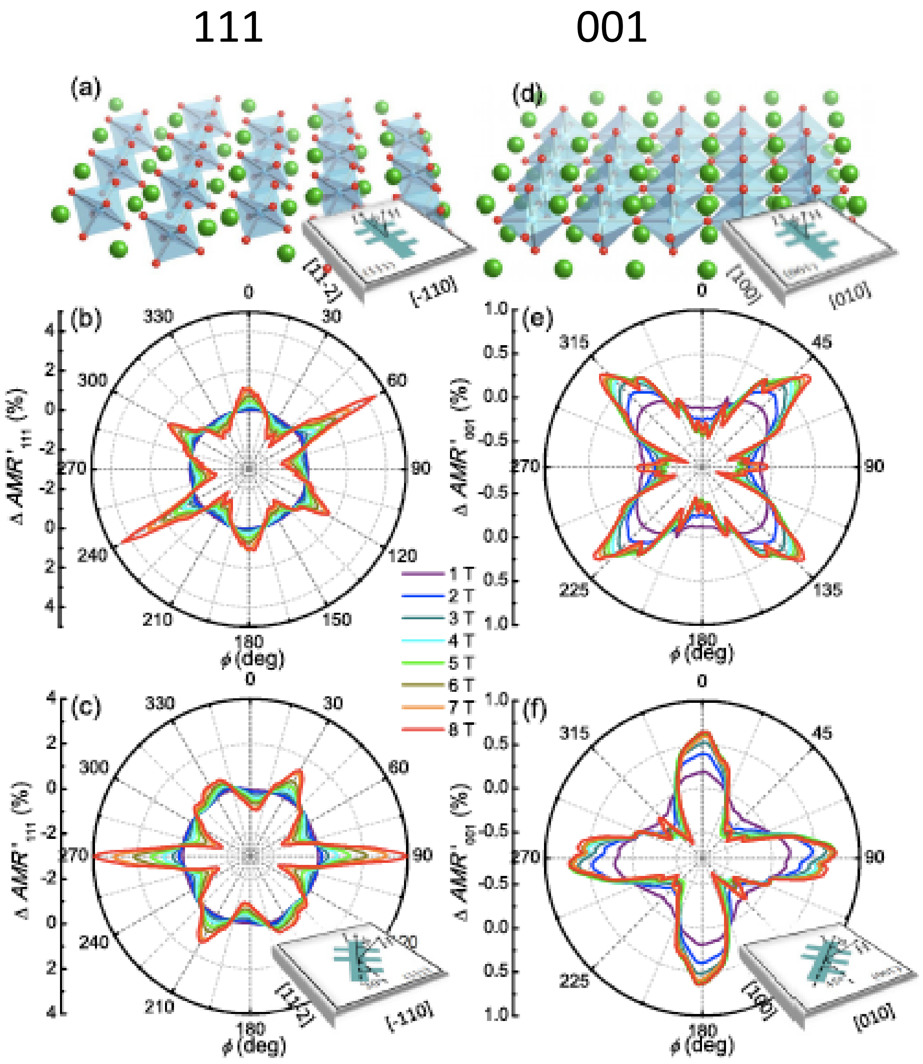
- Triangular layers
- Polar

$$t_{\parallel} \approx 300\text{meV} \qquad t_{\perp} \approx 0.1 t_{\parallel} \qquad n \approx 0.3e/Ti$$

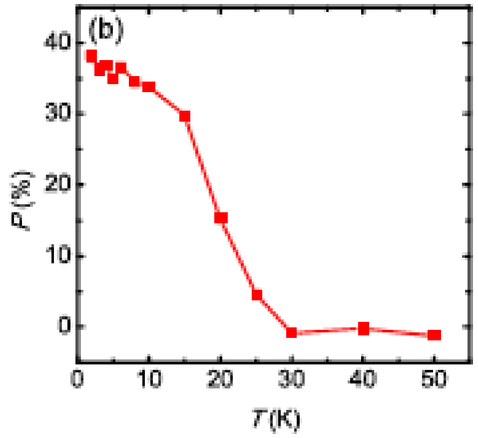
$SrTiO_3$ (111) surface 2DEG

Transport





L. Miao, R. Du, Y. Yin, Qi Li (APL 2016)



n~0.5e/Ti

Transport sees signatures of broken hexagonal symmetry below ~30K (depends on electron density)

- (111) STO is polar = more correlated?
- All t_{2g} orbitals equivalent
- Electron correlation driven nematic?
- Phonon/structural? (Aharony, et al?)

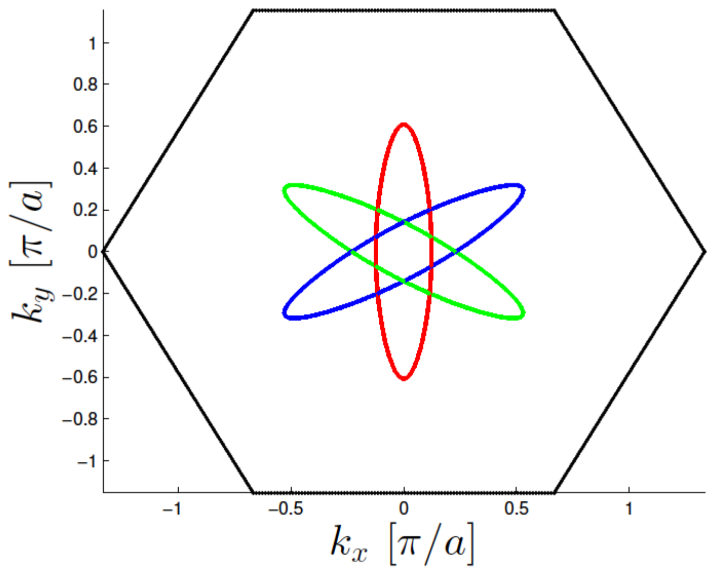
$SrTiO_3$ (111) surface 2DEG

$$\underline{h}(\mathbf{k}) = \begin{pmatrix} \epsilon^c_{\mathbf{k}} + \eta^{ab}_{\mathbf{k}} & \gamma^a_{\mathbf{k}} & \gamma^b_{\mathbf{k}} \\ \gamma^a_{\mathbf{k}} & \epsilon^b_{\mathbf{k}} + \eta^{ca}_{\mathbf{k}} & \gamma^c_{\mathbf{k}} \\ \gamma^b_{\mathbf{k}} & \gamma^c_{\mathbf{k}} & \epsilon^a_{\mathbf{k}} + \eta^{bc}_{\mathbf{k}} \end{pmatrix}$$

Intraorbital

$t_\parallel, t_\perp$

Interorbital



$$H_{\text{int}} = U \sum_{i\ell} n_{i\ell\uparrow} n_{i\ell\downarrow} + \frac{1}{2} V \sum_{i\ell \neq \ell'} n_{i\ell} n_{i\ell'} - \frac{1}{2} J \sum_{i\ell \neq \ell'} \mathbf{S}_{i\ell} \cdot \mathbf{S}_{i\ell'} + \frac{1}{2} J' \sum_{i\ell \neq \ell'} c^\dagger_{i\ell\uparrow} c^\dagger_{i\ell\downarrow} c_{i\ell'\downarrow} c_{i\ell'\uparrow}$$

Interactions might get scaled down by 2DEG “thickness”

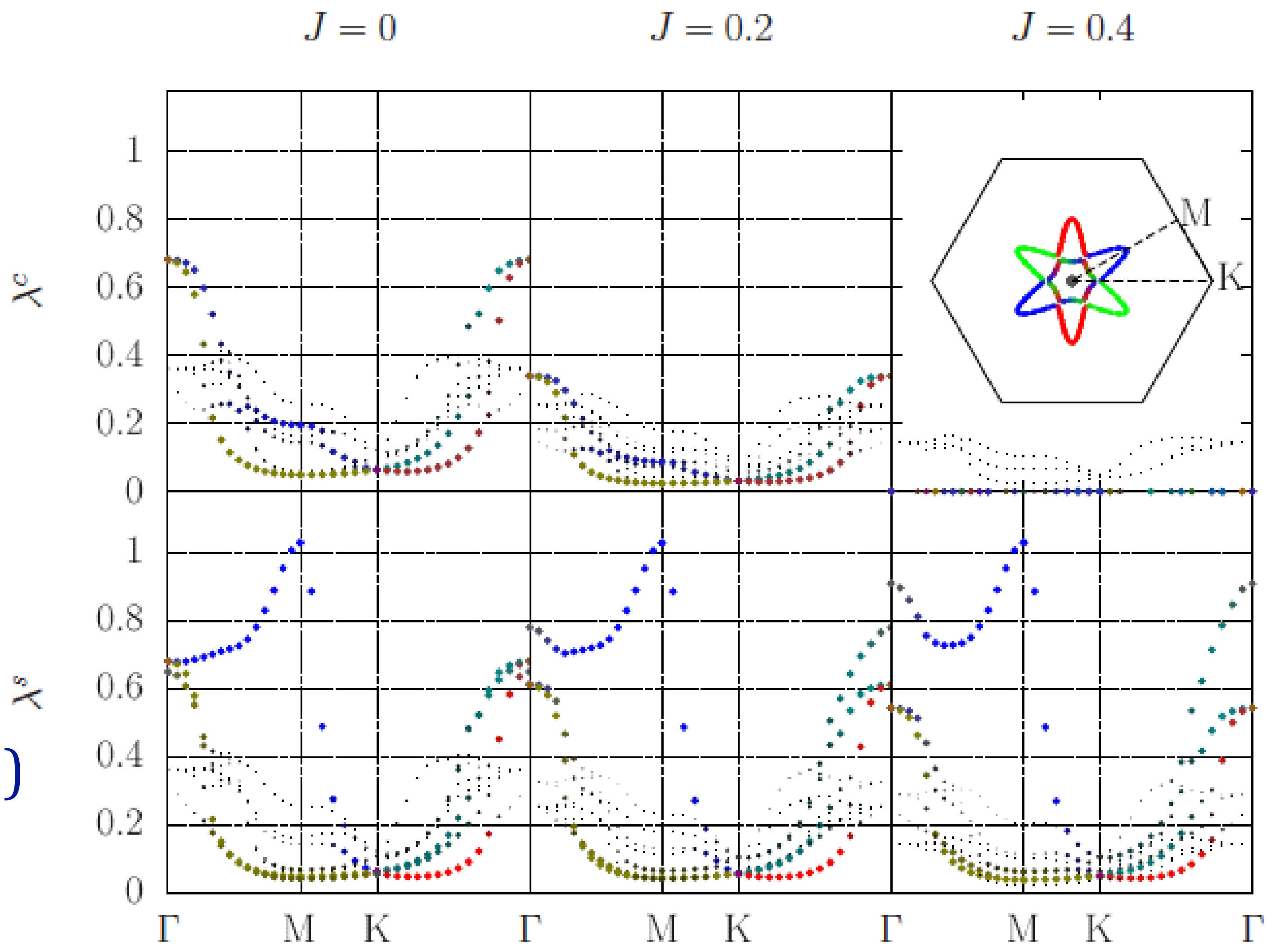
$SrTiO_3$ (111) surface 2DEG

- Generalized RPA calculation
- - Charge, spin, orbital

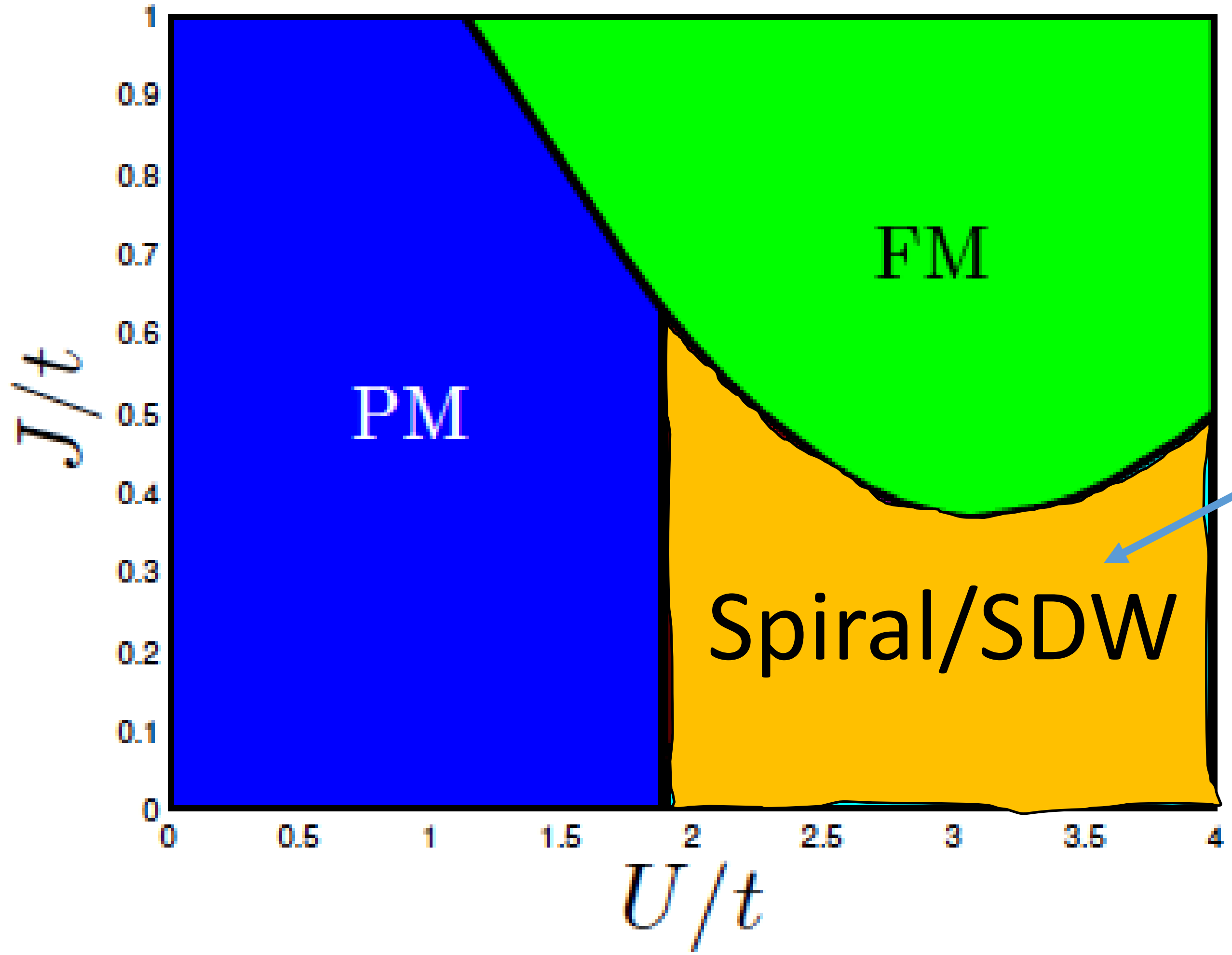
- Susceptibilities ~ orbital diagonal

- Dominant instability ~ spin ($Q=2k_f$) [tips of the ellipse]

- Subdominant ~ charge nematic (Q=0) [doublet]

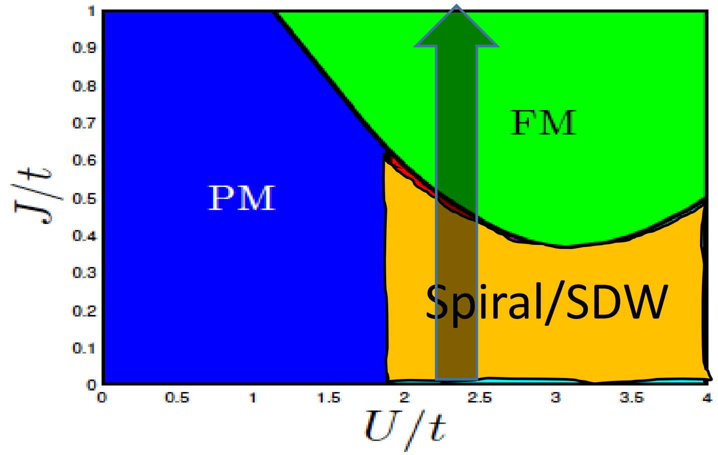


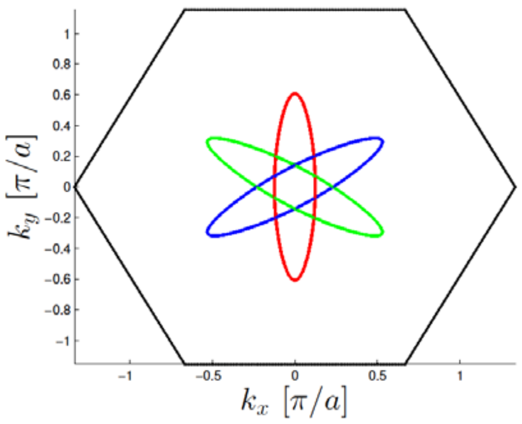
$SrTiO_3$ (111) surface 2DEG

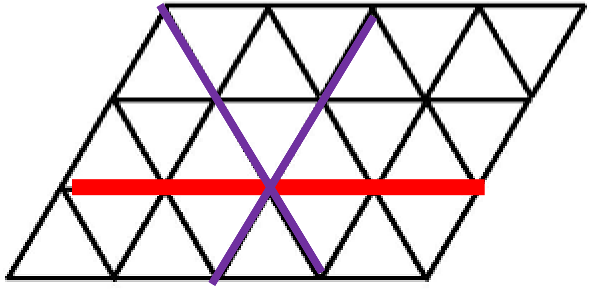


Nematic candidate?

Effective spin model







$$-J_1 \sum_{r,\ell} \vec{S}_\ell(r) \cdot \vec{S}_\ell(r+\delta_\ell^{\parallel}) + J_2 \sum_{r,\ell,\delta_\ell^{\perp}} \vec{S}_\ell(r) \cdot \vec{S}_\ell(r+\delta_\ell^{\perp}) - J_H \sum_{r,\ell<\ell'} \vec{S}_\ell(r) \cdot \vec{S}_{\ell'}(r)$$

Dominant

Weaker

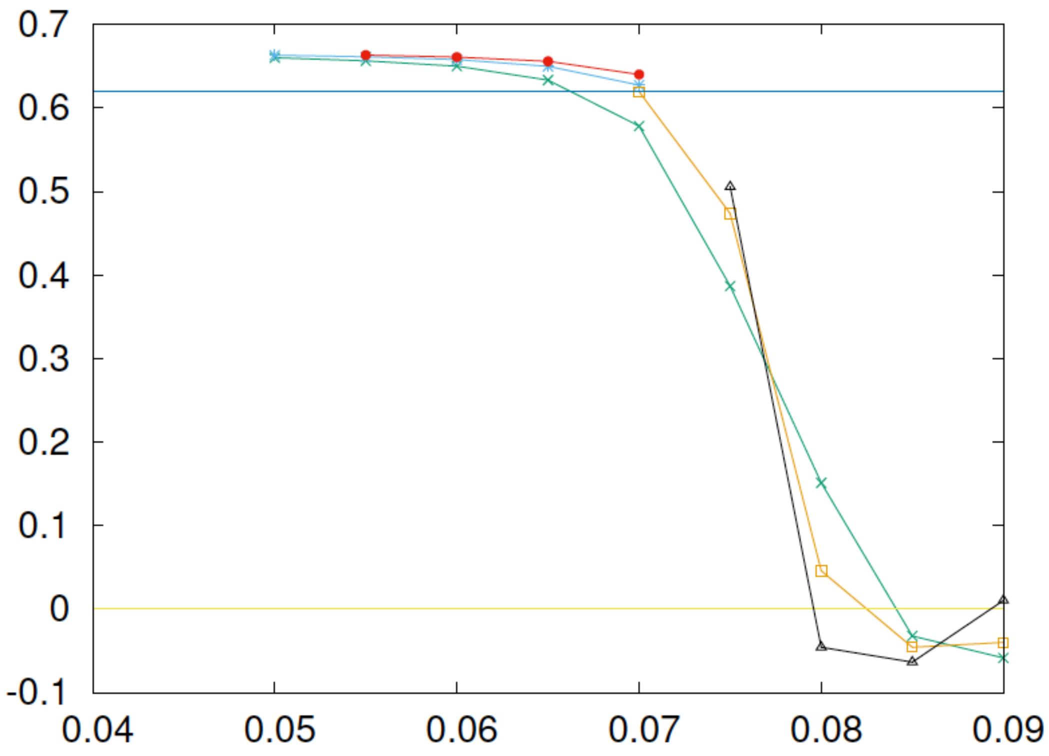
O(9) spin model: Monte Carlo Simulations

$J_{effective}$ ~ scale with (electron density)^2

Effective spin model

Nematic transition: Tc ~ J_2 (interchain coupling)

Binder cumulant



J1 ~ 50 meV

J2 ~ 5 meV

Tc (nematic) ~ 50K