Angle Resolved PhotoEmission Spectroscopy (ARPES) Study of $Sr_4Ru_3O_{10}$ single crystals and Intrinsic Bi_2Te_3 Topological Insulator Thin Films

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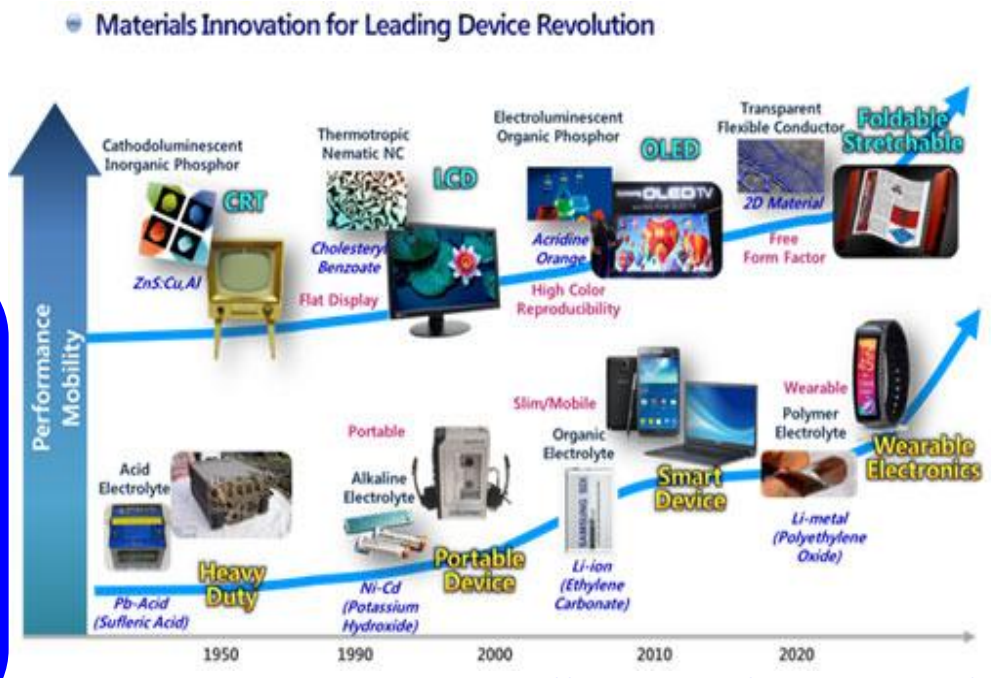
Motivation

- **Understanding the electronic structure of materials:**
  - **Near Fermi level Insights into the solid-state for the materials under investigation**
- **Interesting properties of solids are determined by electrons near Fermi level:**
  - **conductivity,**
  - **magnetoresistance,**
  - **superconductivity,**
  - **Magnetism**

New material with rich Physics and Novel future technological applications:

- **Transition Metal Oxides :**
  - **Oxide Electronics**
- **Topological Insulators :**
  - **Spintronic and quantum computation**



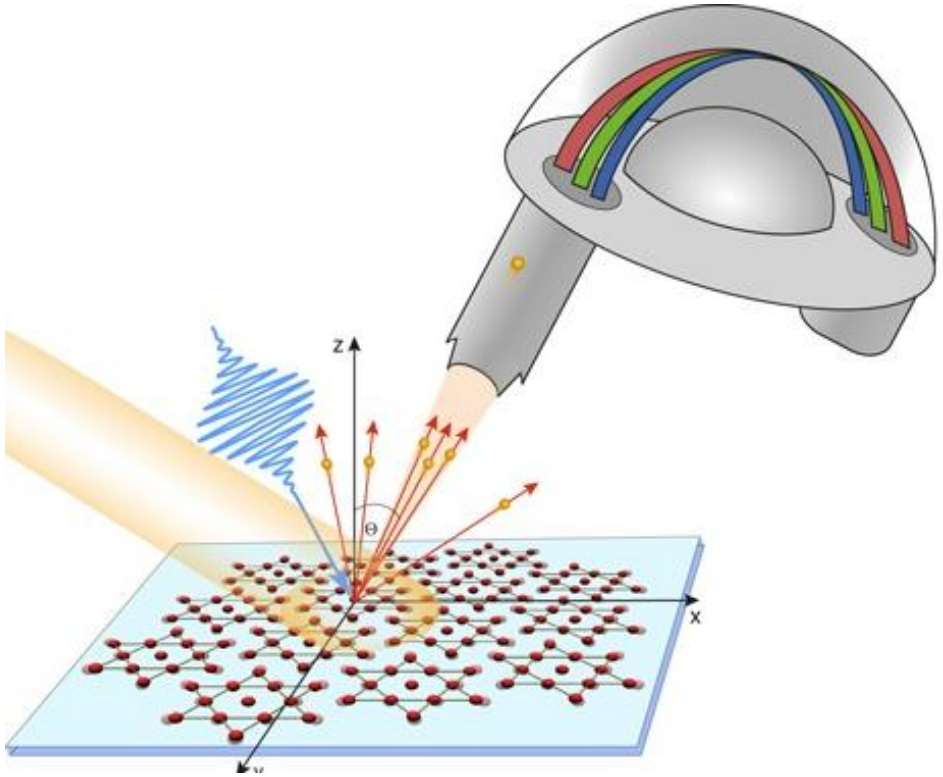
http://www.mrs.org/fall-2014-plenary/

Motivation

- **ARPES: surface sensitive tool to look into the narrow energy slice around Fermi level**

The Light Source:

- **Synchrotron**
- **Laboratory based source**



http://phys.org/news/

Outline

- Introducing angle resolved photoemission spectroscopy (ARPES)
- ARPES Study on $Sr_4Ru_3O_{10}$ Single Crystals with Synchrotron Light Source
- ARPES Study on Intrinsic Bi_2Te_3 Topological Insulator Thin Films with Lab Light Source

Introducing angle resolved photoemission spectroscopy (ARPES)

A. Experimental Considerations

In an ARPES experiment:

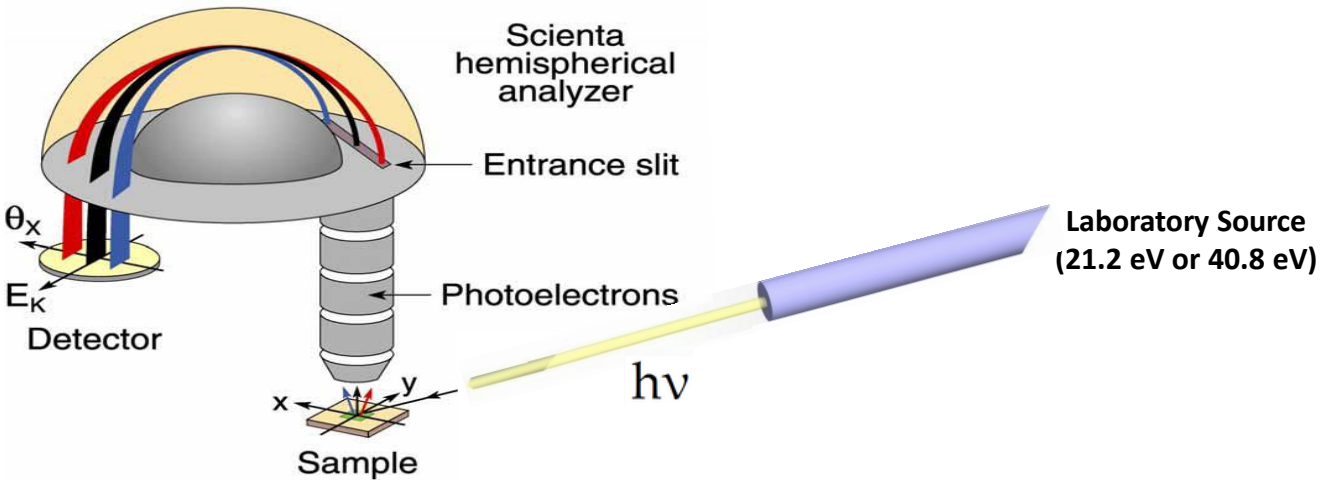
1. **Incoming beam of monochromatic light (U.V or S.X.R) illuminates an atomically flat sample;**

2. **Due to the photoelectric effect, the sample emits electrons;**

3. **The kinetic energy and momentum of these electrons are measured by use of an appropriate instrument;**

4. **The data measured reflect the electronic properties of the material;**

5. **Thus, ARPES measures electronic excitations in solid → band structure.**



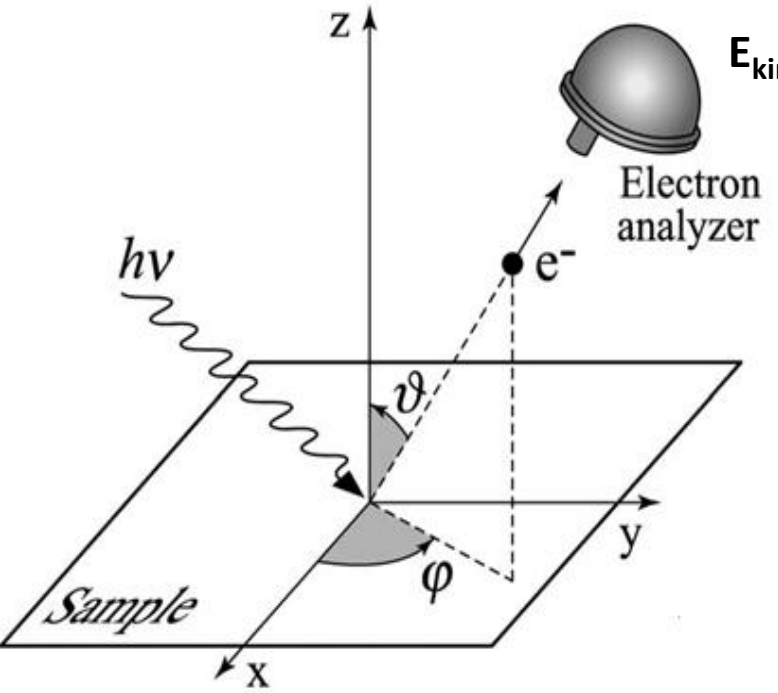
Introducing angle resolved photoemission spectroscopy (ARPES)

B. Theoretical Considerations

Vacuum → **Conservation law** → **Solid**

E_{kin} → $E_f - E_i = h\nu$ → E_B

K → $\mathbf{k}_f - \mathbf{k}_i = \mathbf{k}_{h\nu}$ → **K**



E_{kin}, ϑ, φ

$K = p/\hbar = \sqrt{2m\,E_{kin}}\,/\,\hbar$

$$K_x = \frac{1}{\hbar}\sqrt{2mE_{kin}}\sin\vartheta\cos\varphi$$

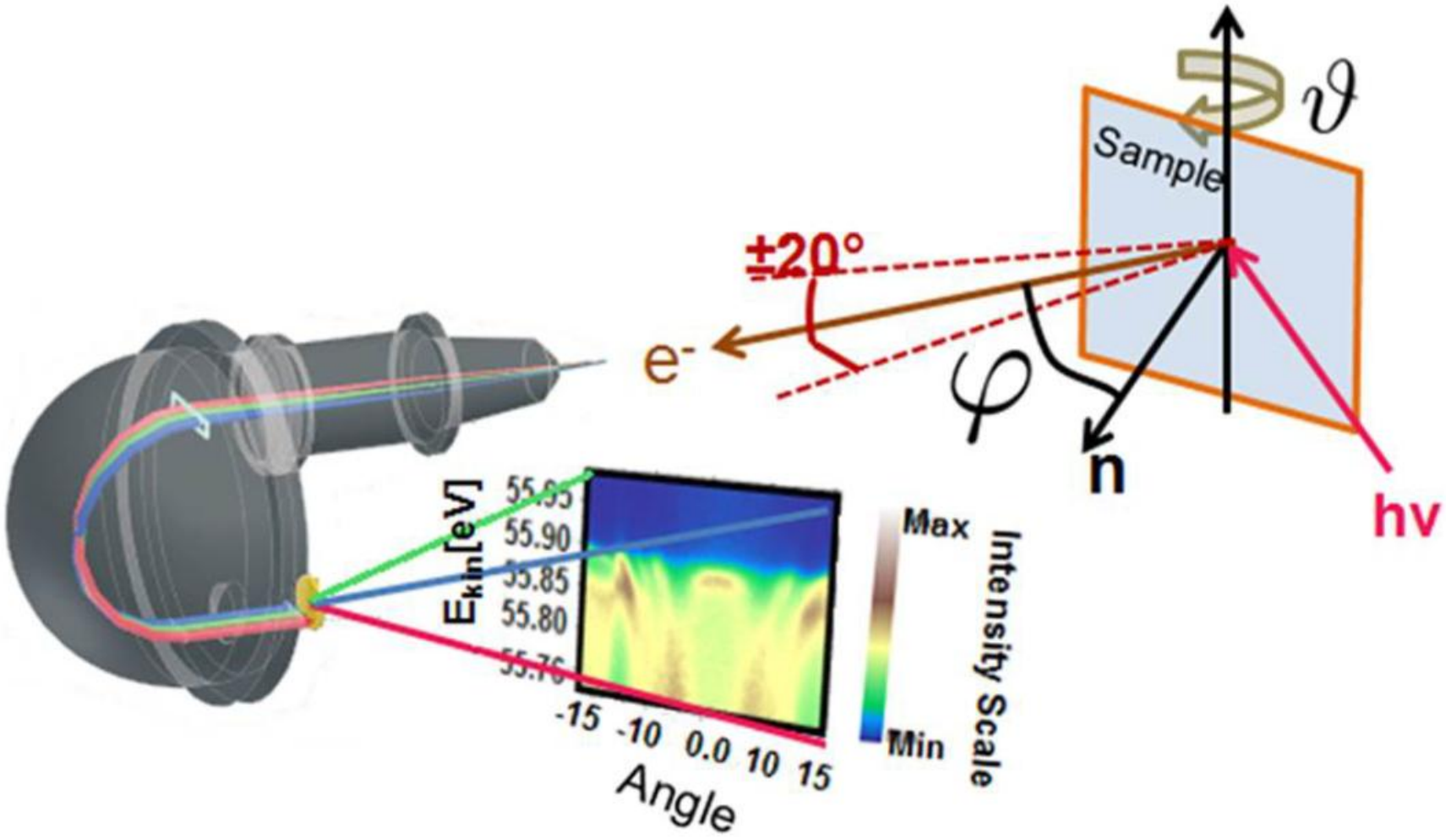
$$K_y = \frac{1}{\hbar}\sqrt{2mE_{kin}}\sin\vartheta\sin\varphi$$

$$K_z = \frac{1}{\hbar}\sqrt{2mE_{kin}}\cos\vartheta$$

A. Damascelli., *Physica Scripta* ***T109***, *61 (2004)*

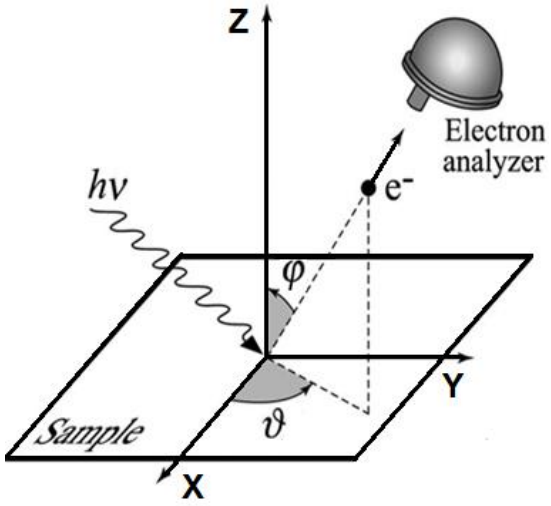
Introducing angle resolved photoemission spectroscopy (ARPES)

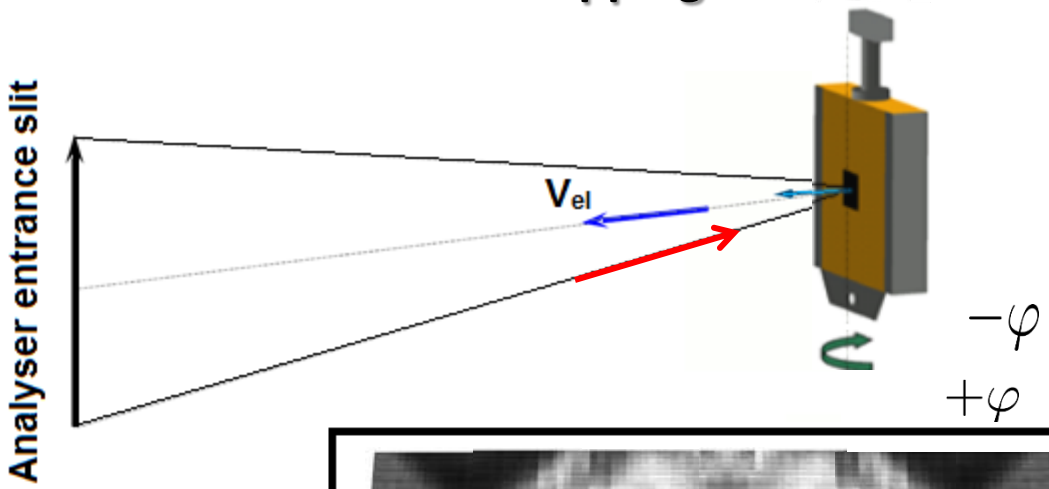
C. Data collection: From Energy Analyzer to 2D maps

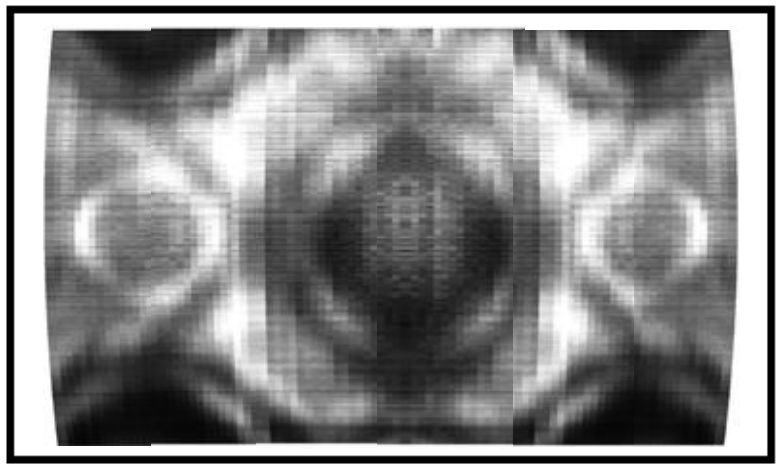


Introducing angle resolved photoemission spectroscopy (ARPES)

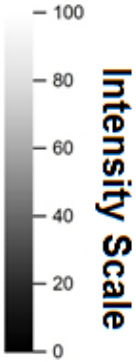
C. Data collection: Fermi Surface Mapping

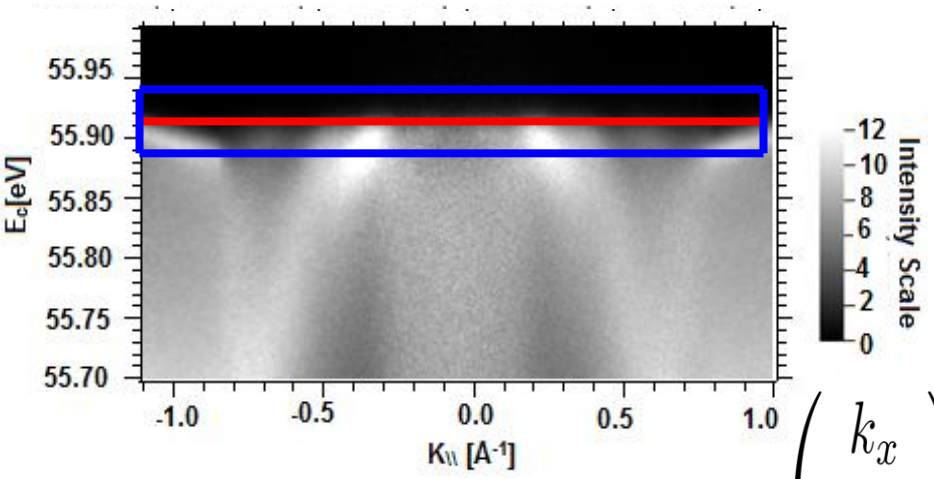






k_y





k_x

$\varphi_1\ \varphi_2\ \varphi_3\ \varphi_4\ \varphi_5\ \cdots\ \varphi_n$

$$\begin{pmatrix} k_x \\ k_y \\ 0 \end{pmatrix} = \begin{pmatrix} \cos\varphi & 0 & -\sin\varphi \\ 0 & 1 & 0 \\ \sin\varphi & 0 & \cos\varphi \end{pmatrix} \begin{pmatrix} 0 \\ |\mathbf{k}|\sin\vartheta \\ |\mathbf{k}|\cos\vartheta \end{pmatrix}$$

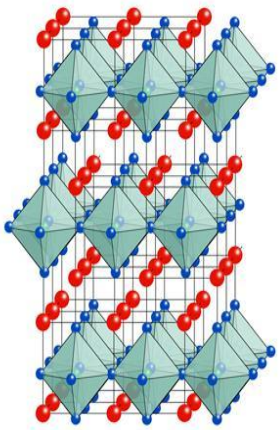
ARPES Study on $Sr_4Ru_3O_{10}$ Single Crystals with Synchrotron Light Source

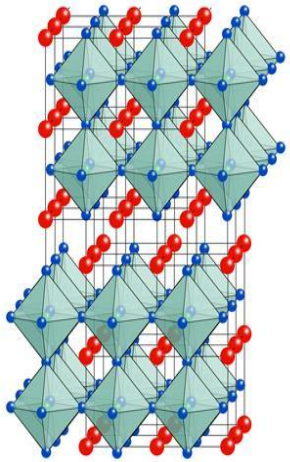
General Introduction to $Sr_{n+1}Ru_nO_{3n+1}$

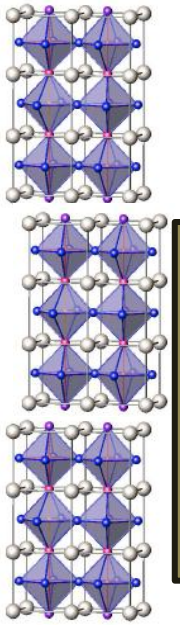
$Sr_{n+1}Ru_nO_{3n+1}$

$n=1$ $n=2$ $n=3$ $n=\infty$

Sr_2RuO_4 $Sr_3Ru_2O_7$ $Sr_4Ru_3O_{10}$ $SrRuO_3$







- Ferromagnetic
- T_c = 160 K.

Spin-triplet superconductor (T_c=1.5K)

Close to ferromagnetism, metamagnetic transition QCEP

- **Probe the near Fermi level electronic structure of $Sr_4Ru_3O_{10}$ (including the Fermi surface topology) using ARPES**
- **Microscopic origin of metamagnetic behavior in $Sr_4Ru_3O_{10}$**

K. Ishida *et al*., Nature **396** (1998).

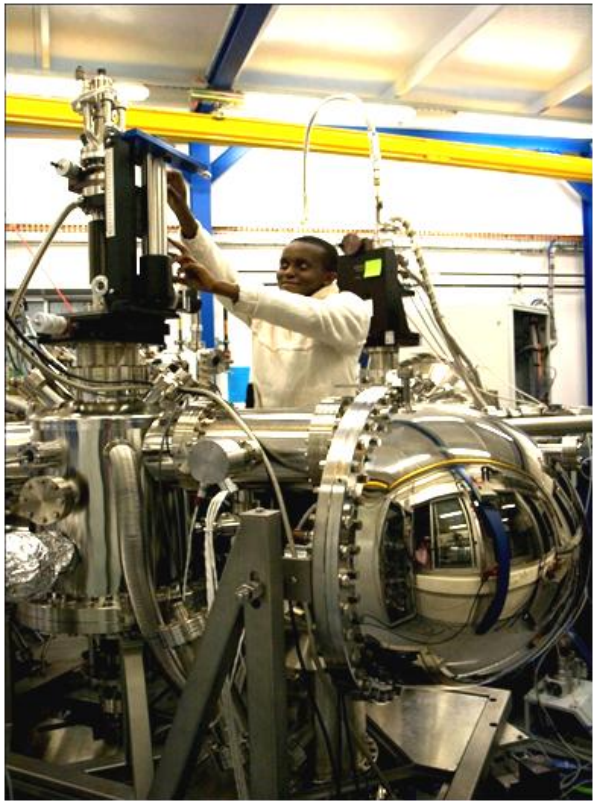
S. A Grigera *et a*l., Science **294 ,** 329(2001).

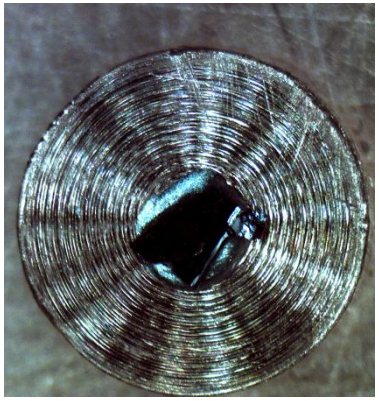
Y. J. Jo *et al.,* Phys. Rev. B **75**, 0944413(2007)

ARPES Study on $Sr_4Ru_3O_{10}$ Single Crystals with Synchrotron Light Source

ARPES Experiment at Soleil

Beamline CASSIOPÉE



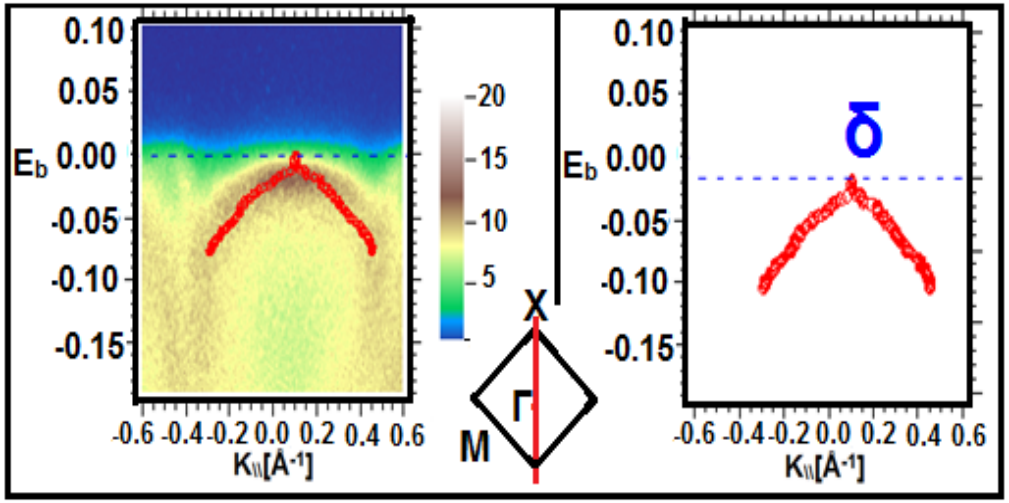


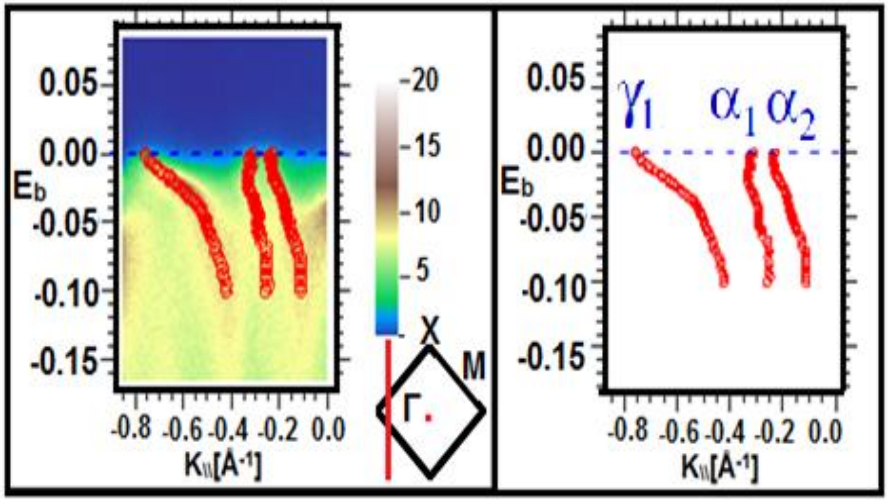
- Single crystals of $Sr_4Ru_3O_{10}$ cleaved *in situ* at the measurement temperature of 5 K;
- kept in ultra-high vacuum conditions (~ $5x10^{-10}$ mbar) to avoid surface contamination;

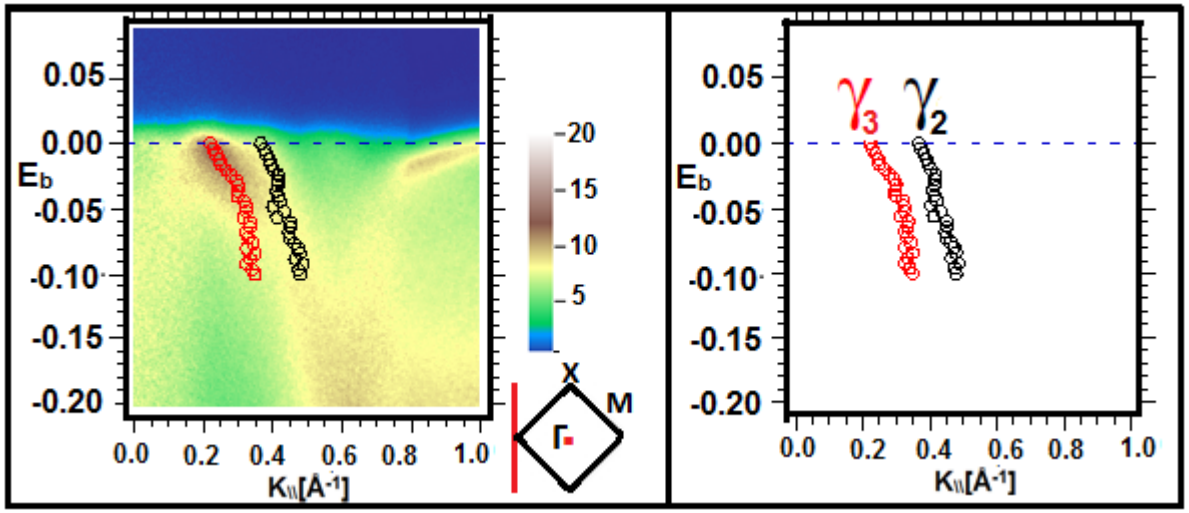
ARPES Study on $Sr_4Ru_3O_{10}$ Single Crystals with Synchrotron Light Source

Results: E_f crossing

- Six bands crossing the Fermi level, then giving rise to six Fermi Surface Sheets





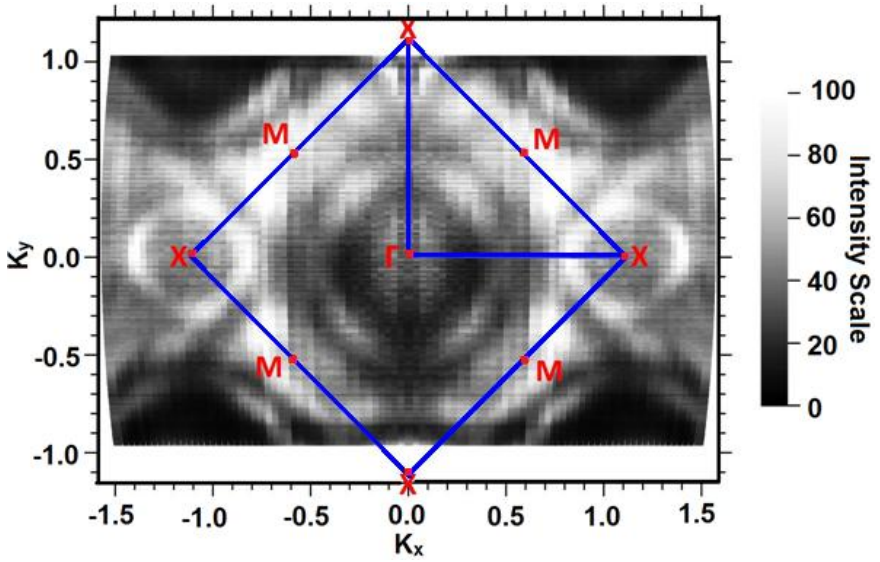


P. Ngabonziza *et al*., Proceeding of the SA Institute of Physics (2012)

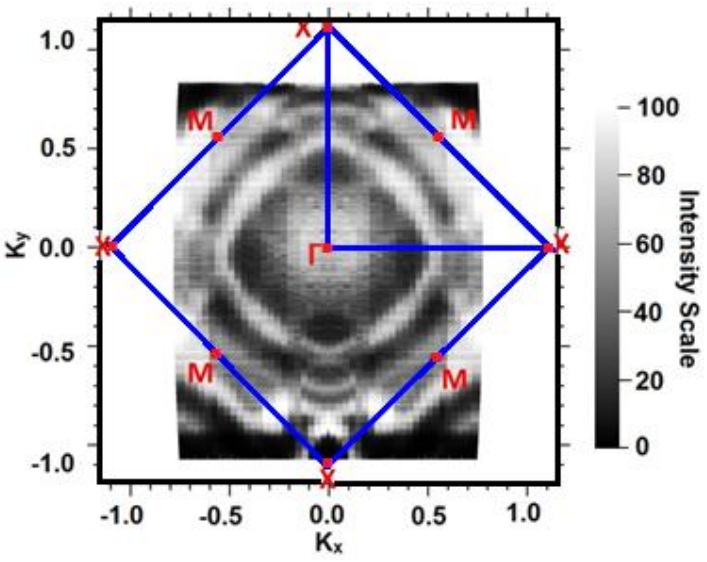
ARPES Study on $Sr_4Ru_3O_{10}$ Single Crystals with Synchrotron Light Source

Results: Fermi Surface Mapping High Symmetry Points in the BZ

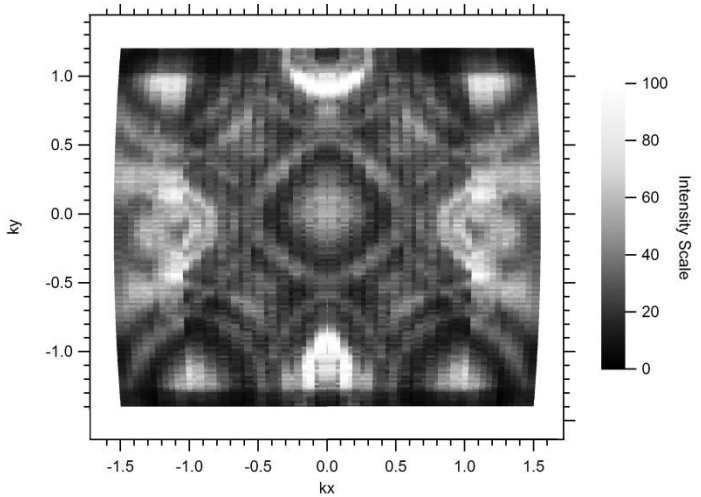
Sample-1 at 60 eV in LHP



Sample-2 at 60 eV in LHP

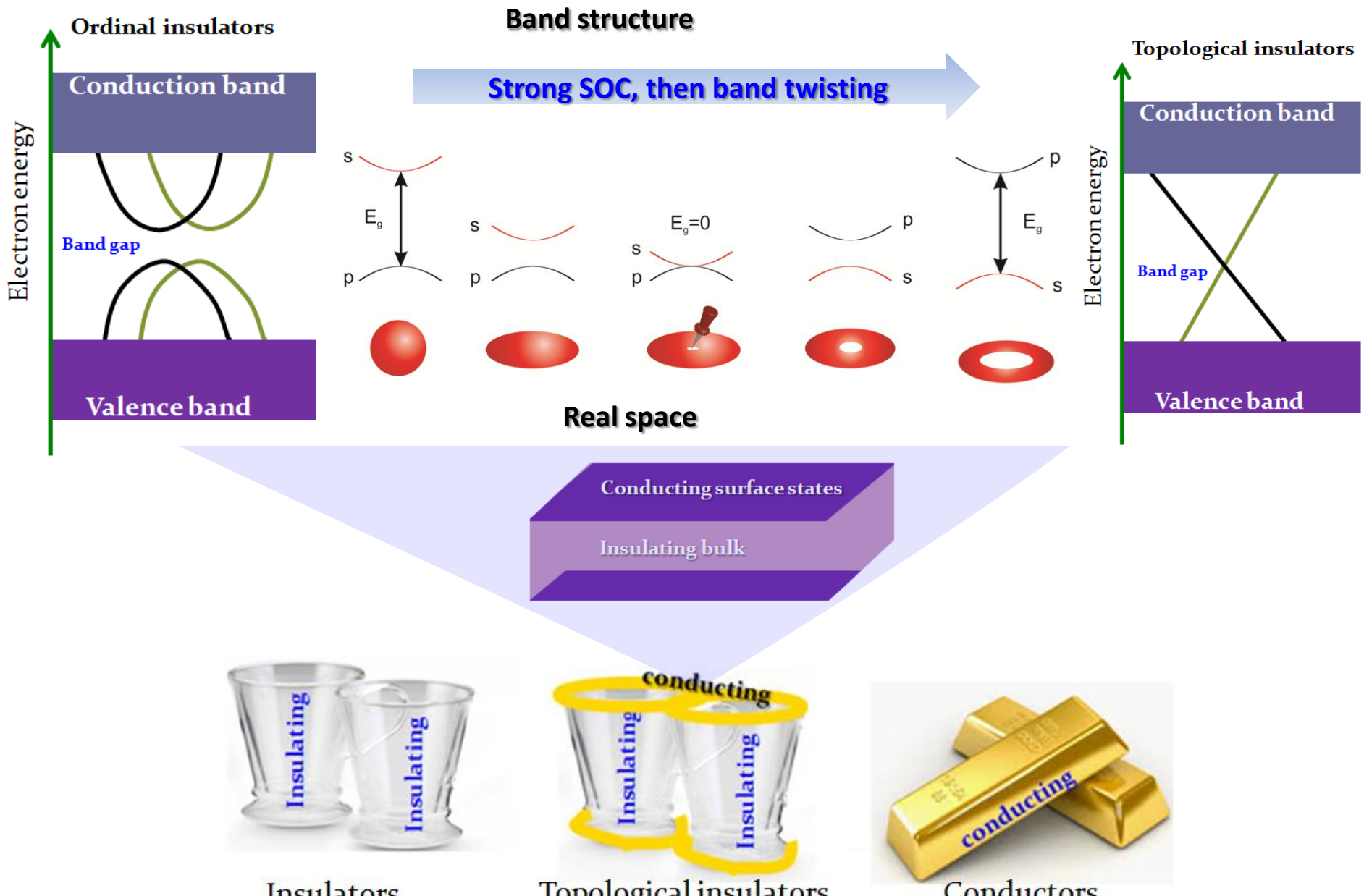


Sample-2 at 110 eV in LVP



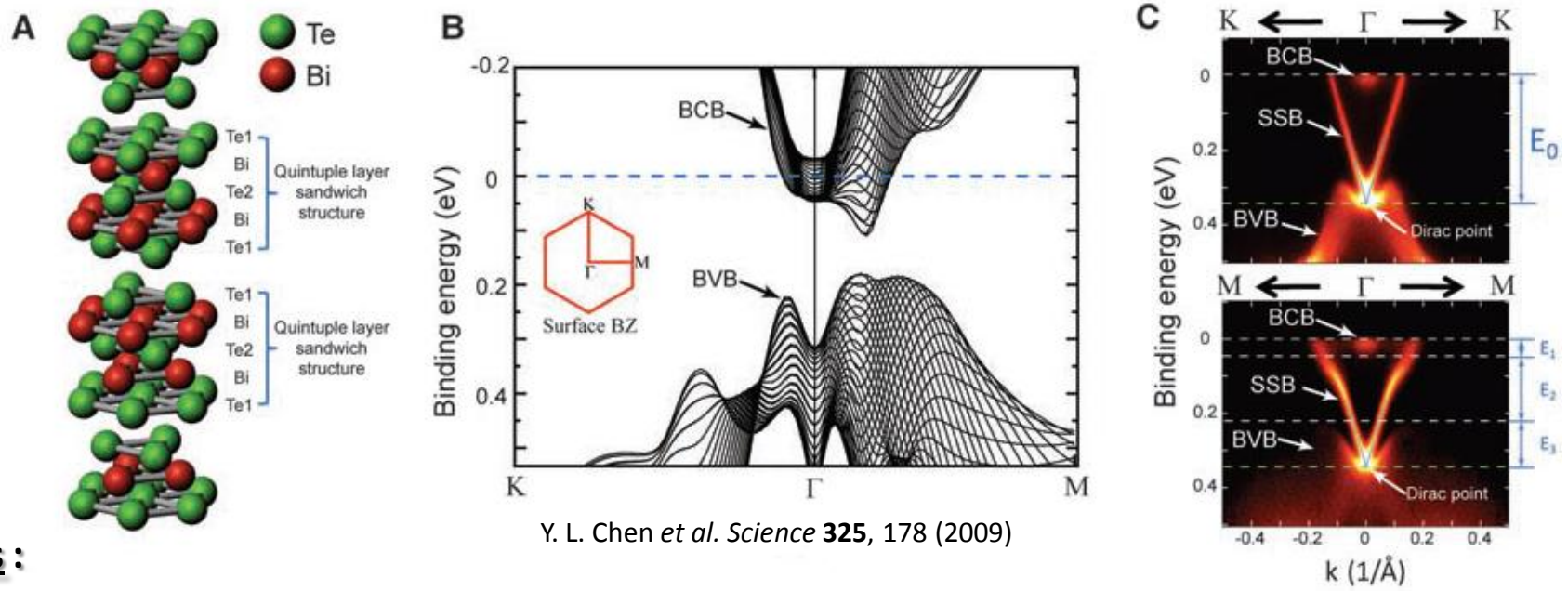
ARPES Study on Intrinsic Bi_2Te_3 Topological Insulator Thin Films with Lab Light Source

- **Normal and topological insulators**



ARPES Study on Intrinsic Bi_2Te_3 Topological Insulator Thin Films with Lab Light Source

➢ **Current challenges in the field: Bulk single crystals vs Thin films**



Y. L. Chen *et al. Science* **325**, 178 (2009)

Issues :

- Bulk conduction:
  - ❑ **Complicate** direct observation of surface effects
- Doping/counter-doping
  - ❑ **Defects** introduction
  - ❑ **Low** surface mobility

✓ **Thin films:**

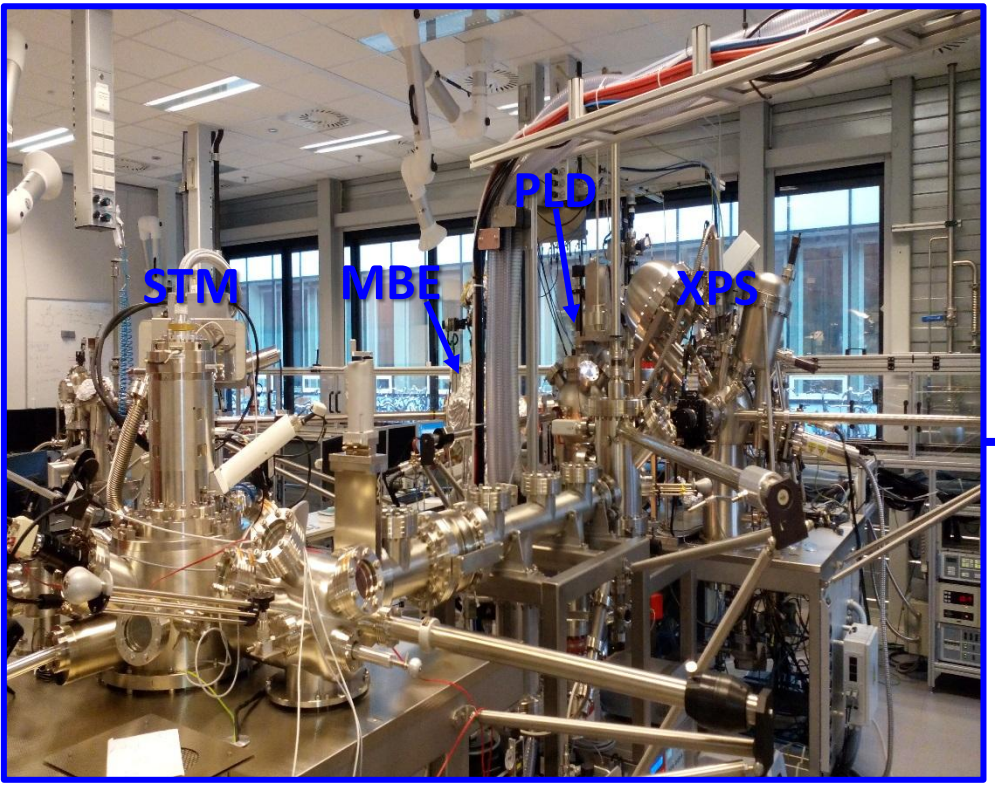
- **Bulk insulating thin films (ARPES),**
- **In-situ Capping,**
- **Top and bottom gate,**
- **Normal state transport (HBs) and JJs**

M. Veldhorst *et al.*, Nat. Mater. **11**, 417 (2012)

M. Snelder *et al.*, Supercond. Sci. Technol. **27**, 104001 (2014)

ARPES Study on Intrinsic Bi_2Te_3 Topological Insulator Thin Films with Lab Light Source

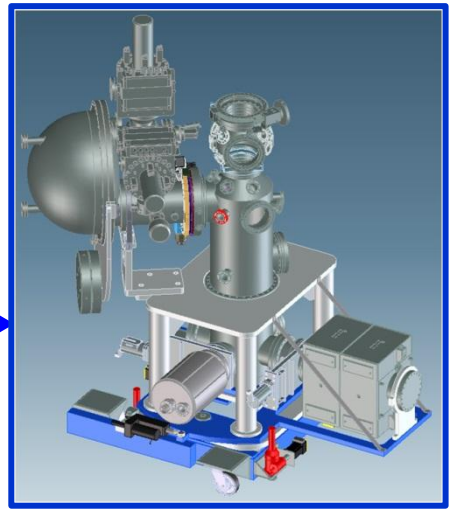
- **Combined system for growth and *in-situ* characterizations**



UHV conditions

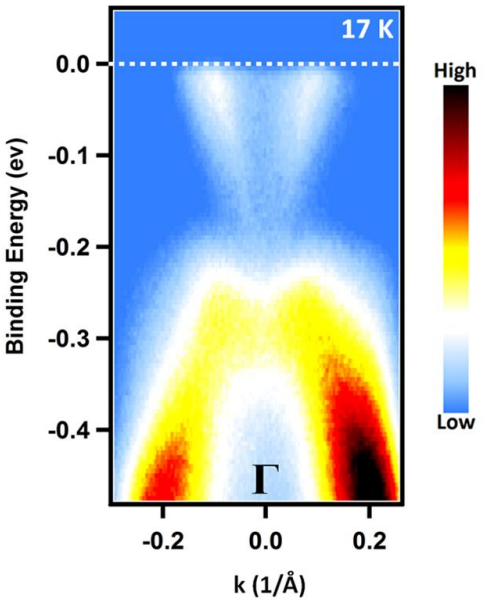
~$2x10^{-10}$ mbar

ARPES-Lab source

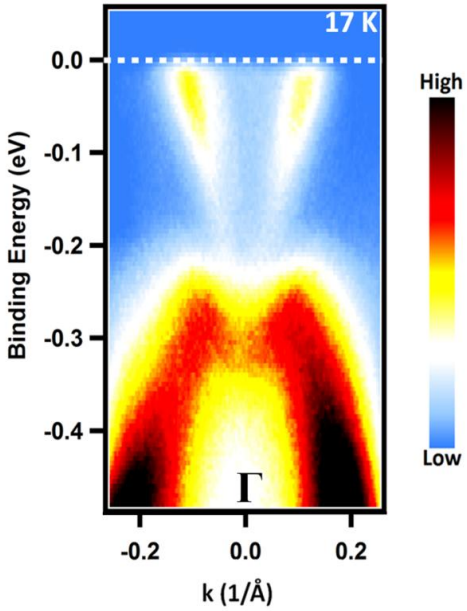


ARPES Study on Intrinsic Bi_2Te_3 Topological Insulator Thin Films with Lab Light Source

20 nm Bi_2Te_3/Al_2O_3

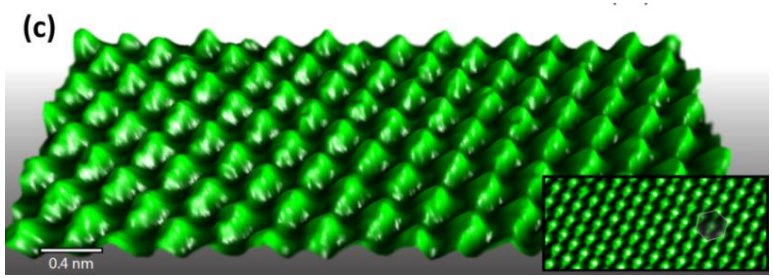


15 nm $Bi_2Te_3/SrTiO_3$



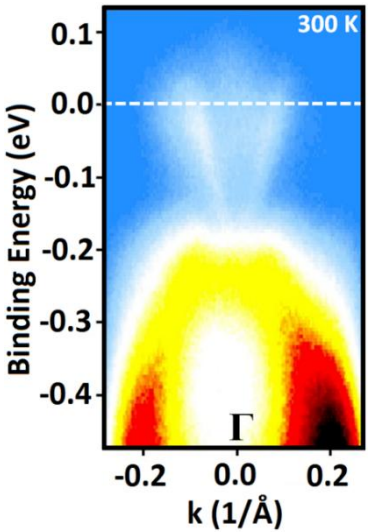
In-situ STM

30 nm Bi_2Te_3/Al_2O_3

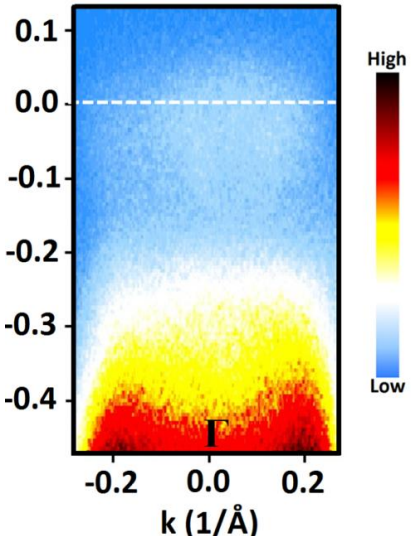


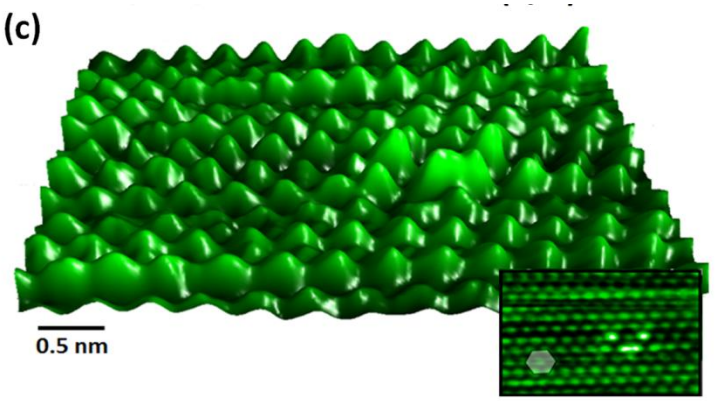
20 nm Bi_2Te_3/Al_2O_3

(a) Before exposure



(b) After 10 min exposure



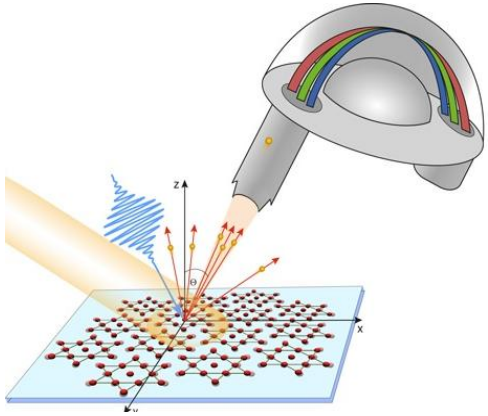


P. Ngabonziza et al., Phys. Rev. B **92**, 035405 (2015)

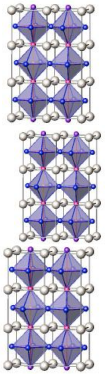
Summary

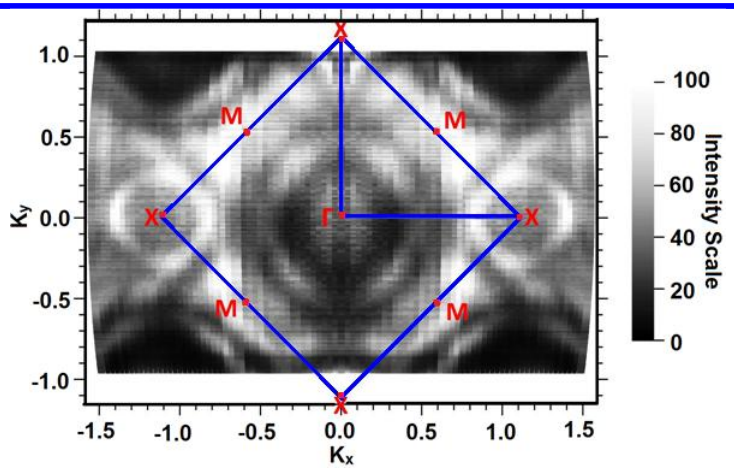
The Light Source:

- **Synchrotron**
- **Laboratory based source**



$Sr_4Ru_3O_{10}$





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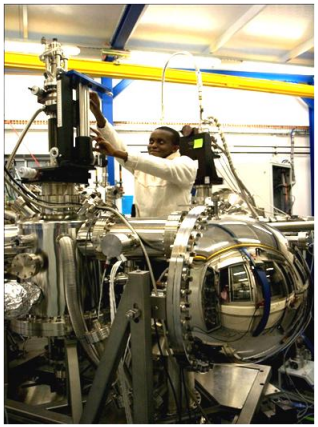
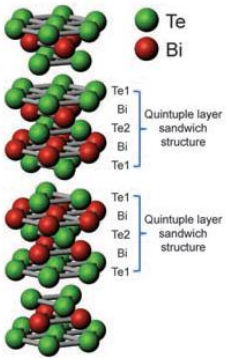
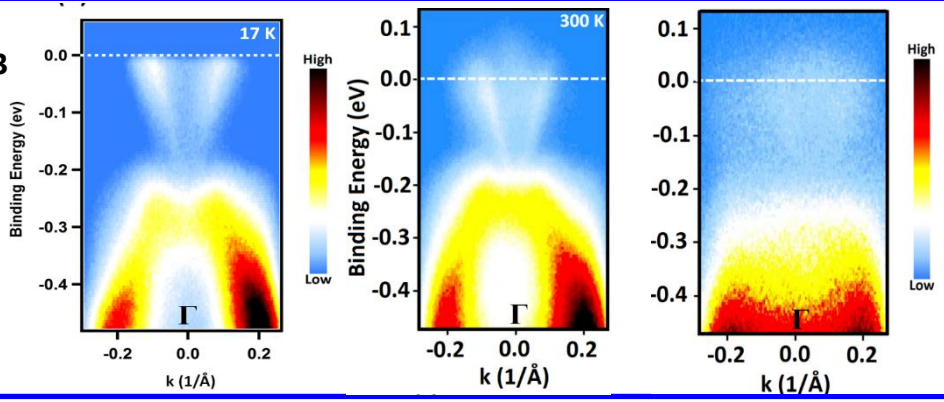




Bi_2Te_3



Laboratory based source


THANK
YOU