Thin-Film Pyrochlore Iridates

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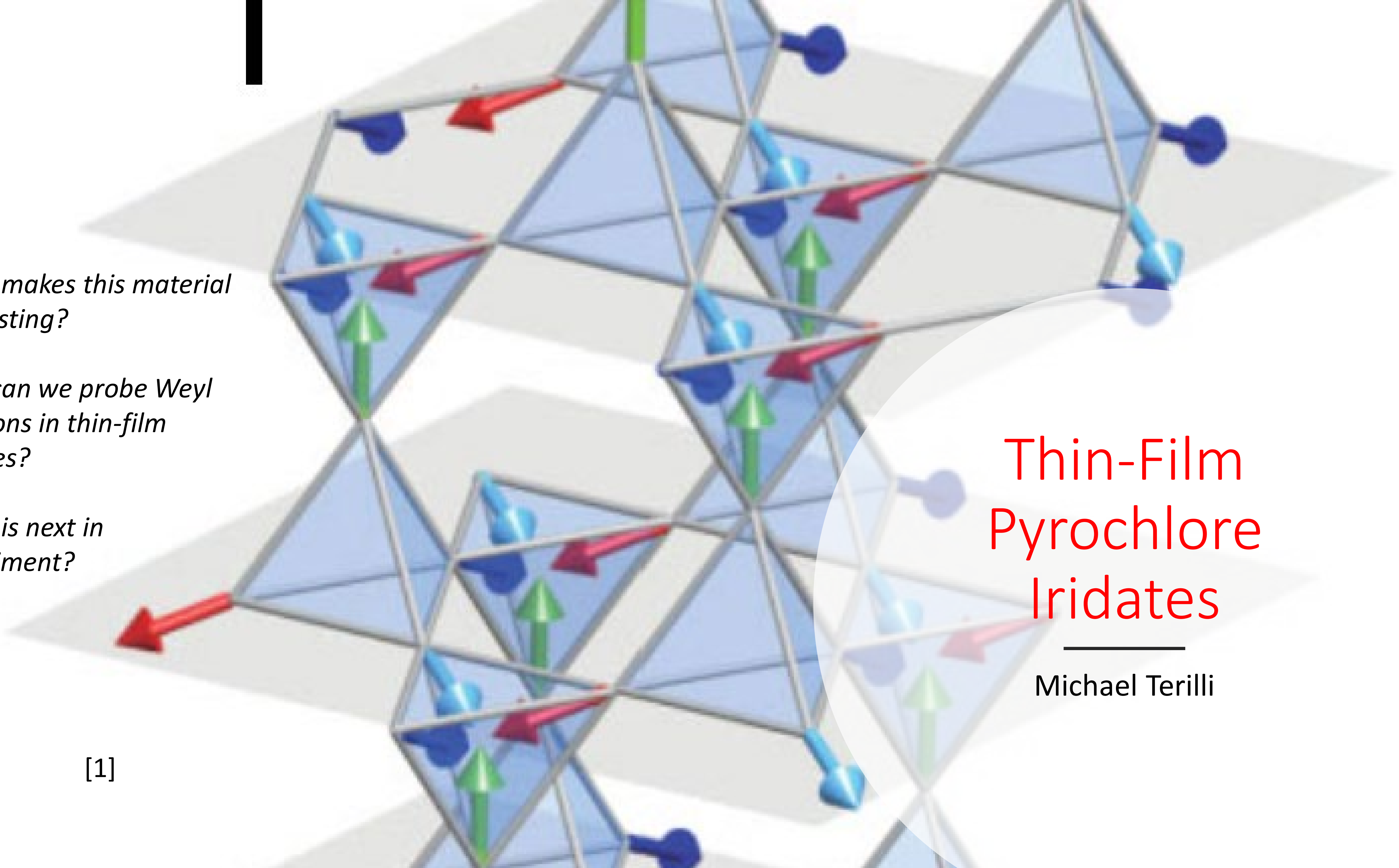
What makes this material interesting?

How can we probe Weyl fermions in thin-film iridates?

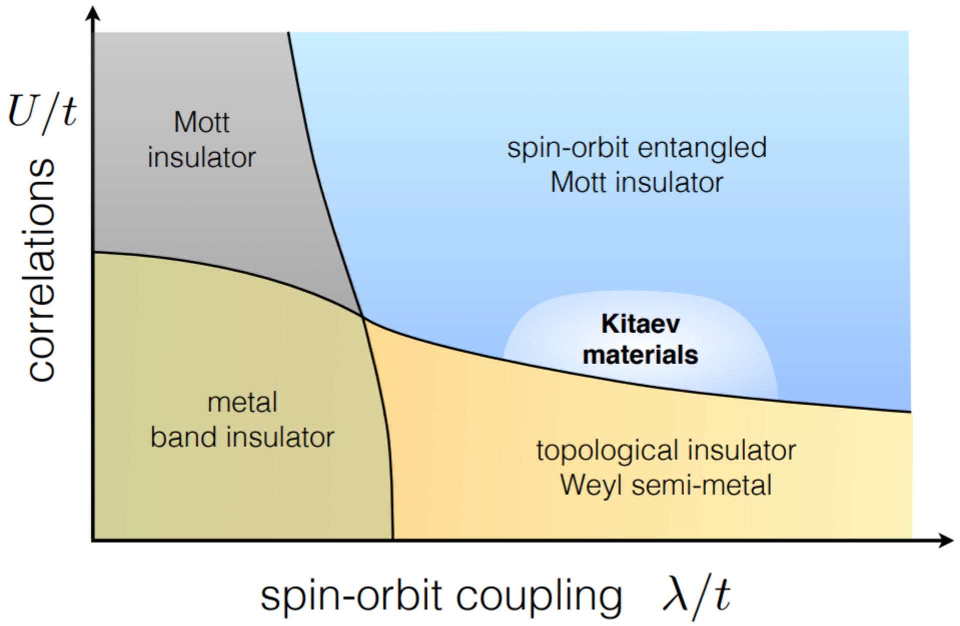
What is next in experiment?

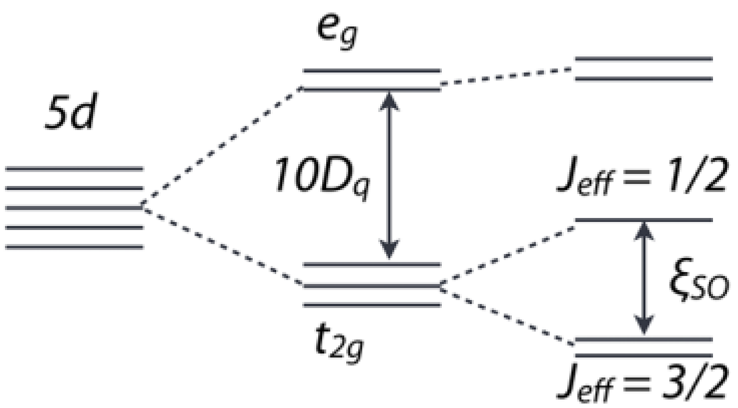


[1]

Introduction

- Defined by **strong spin-orbit coupling** plus **correlations**
- Films allow for control of interesting phases
    - Strain
    - Gating
    - Dimensionality

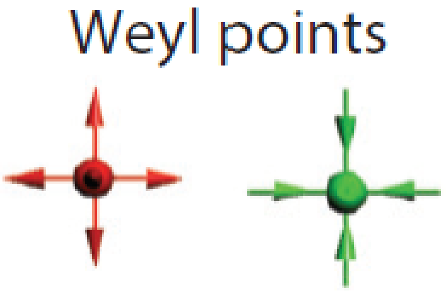


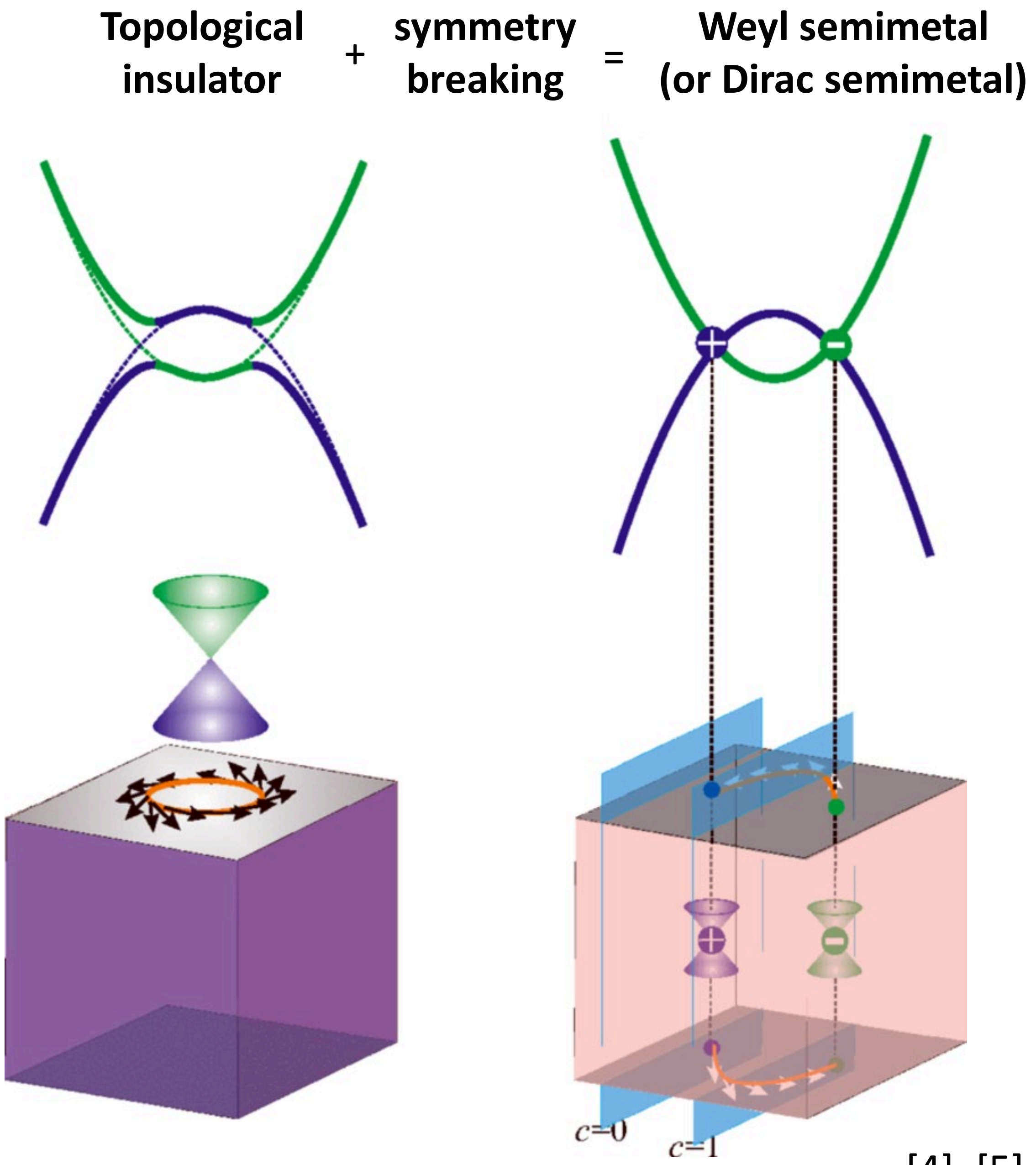


[2], [3]

Weyl semimetal (WSM)

- Forms by breaking time-reversal or inversion symmetry
- Band structure characterized by:
  - Weyl points near Fermi surface in the bulk
  - Fermi arcs on the surface
- How do we measure band structure?





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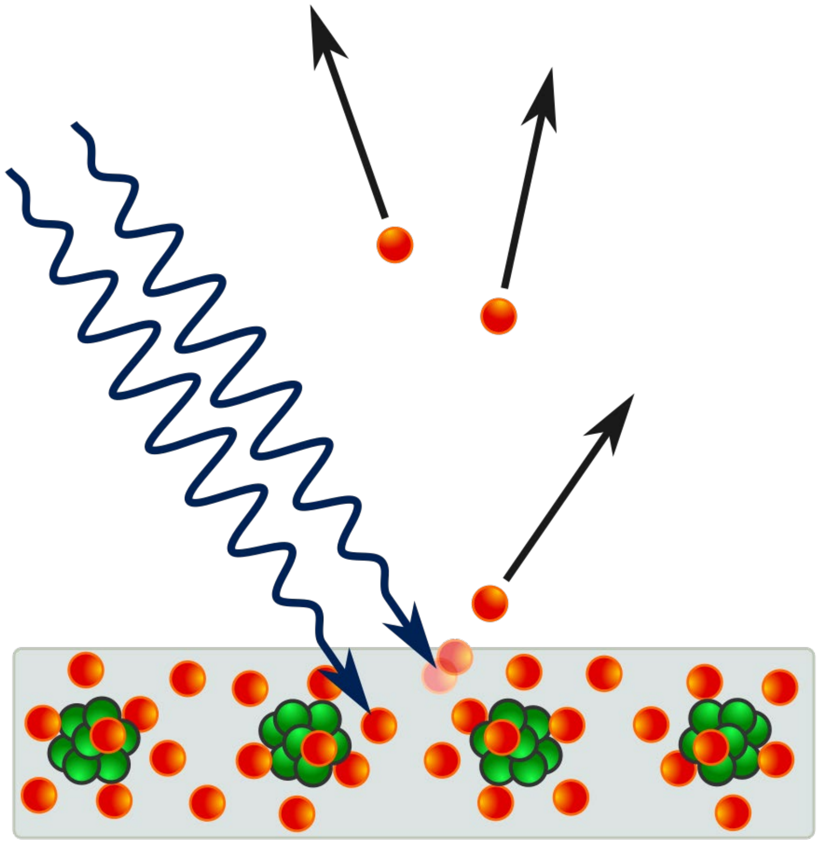
Angle-resolved photoemission spectroscopy (ARPES) background: Photoelectric effect

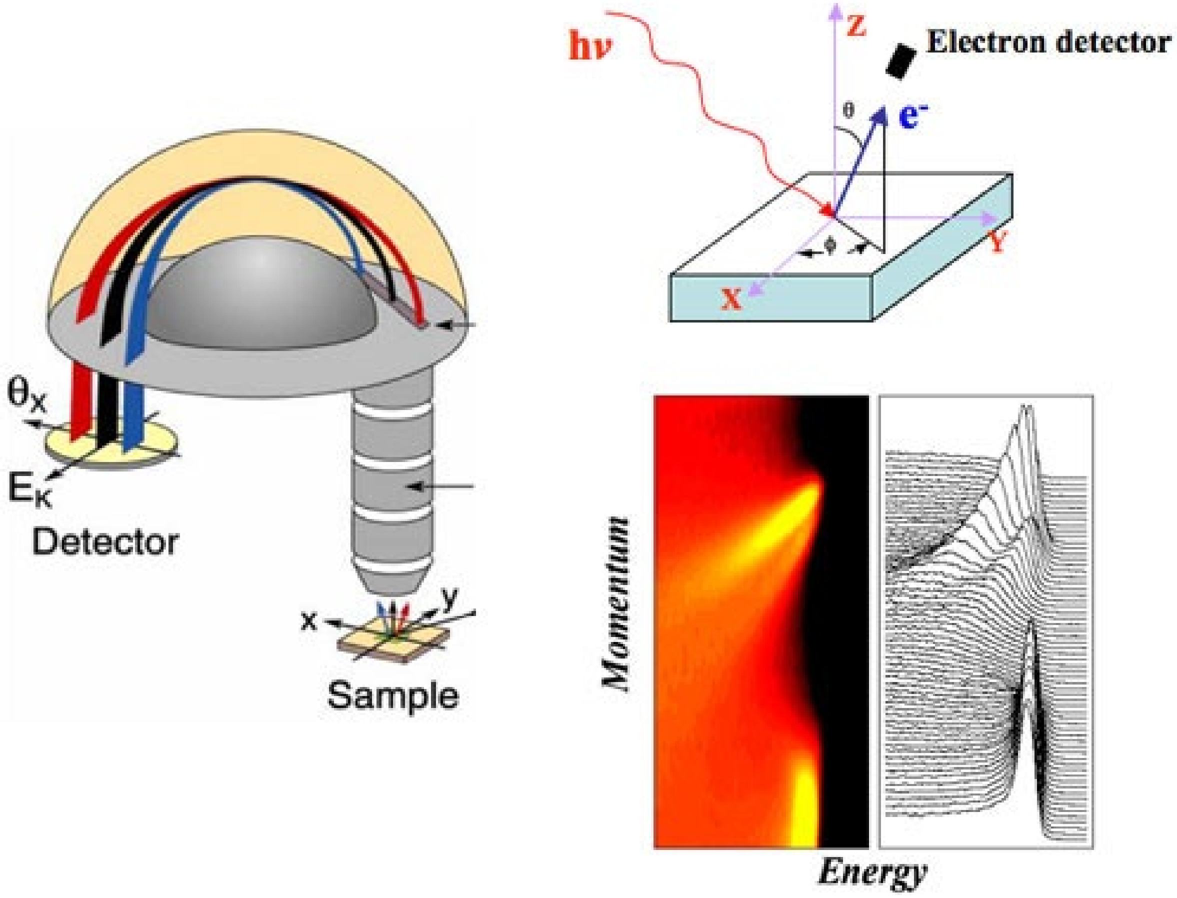
- $K_{max} = \hbar\omega - \phi - E_B$
  - ϕ: work function
  - E_B: binding energy
- Photoemission spectroscopy (PES)
  - Measure the energy of photoelectrons to construct density of states



https://en.wikipedia.org/wiki/Photoelectric_effect

ARPES

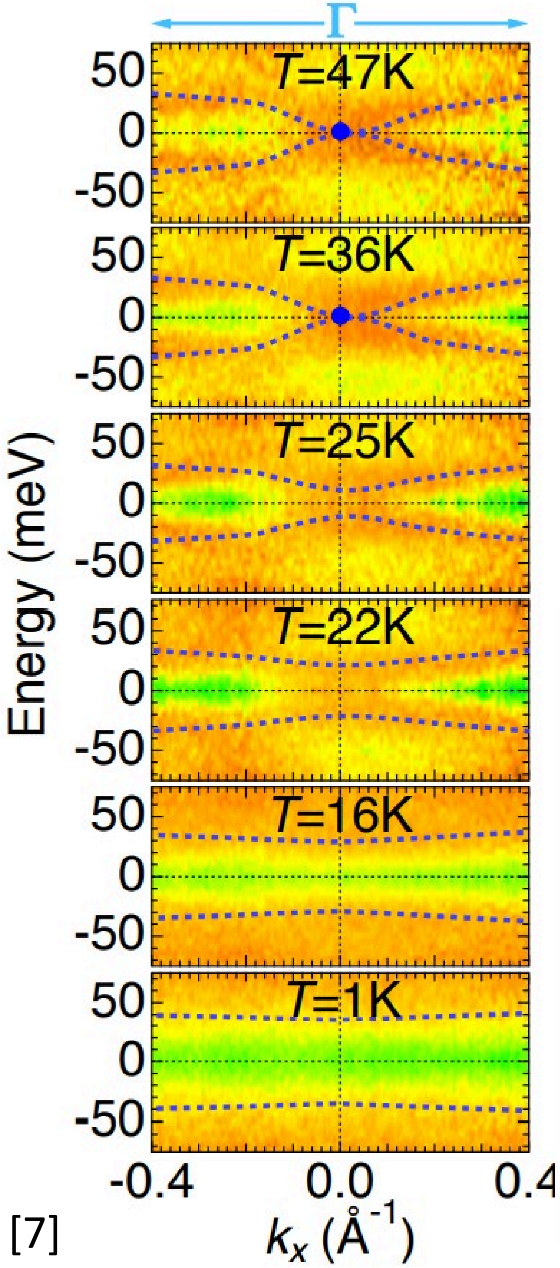
- Angle gives momentum resolution
- **ARPES is one of the most direct methods for measuring E(k) (band structure)**
- Surface sensitive -> perfect for topological materials
- What have we seen from ARPES measured on thin-film iridates?

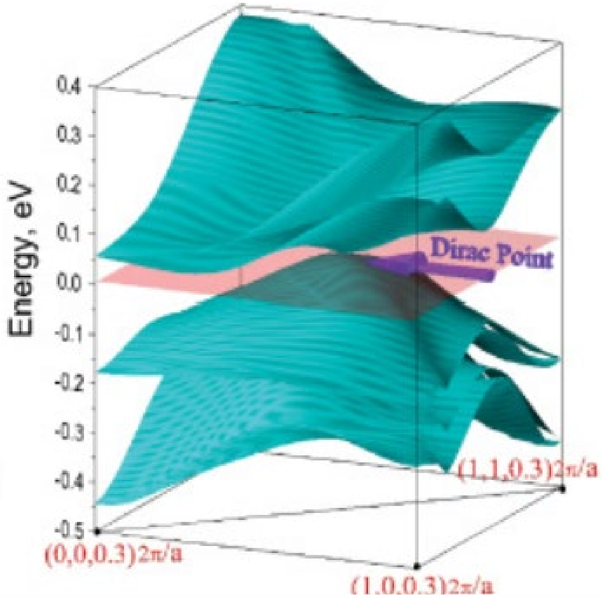


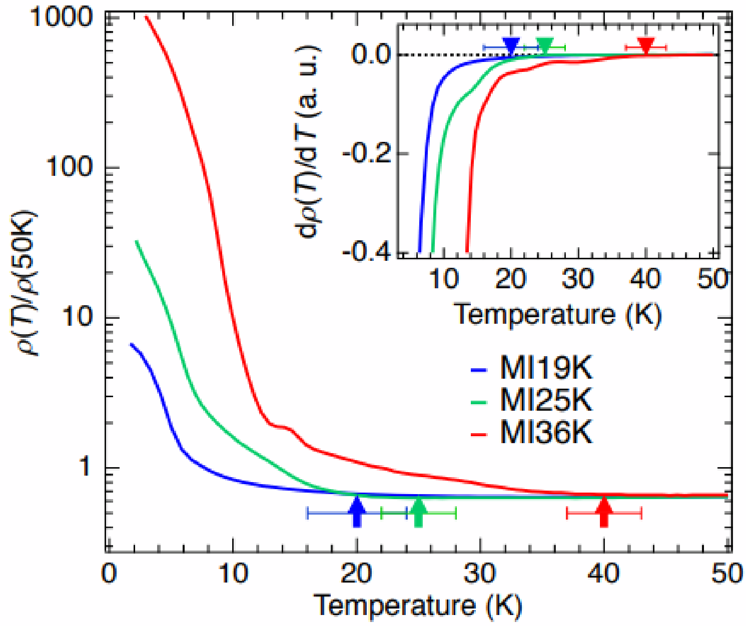
Taken from Shen Lab, Stanford

ARPES on $Nd_2Ir_2O_7$

- By symmetry breaking, can manipulate quadratic touching point -> WSM state
- Theoretical calculations predict **Weyl points**
- However, in experiment, low-temperature state is **gapped**







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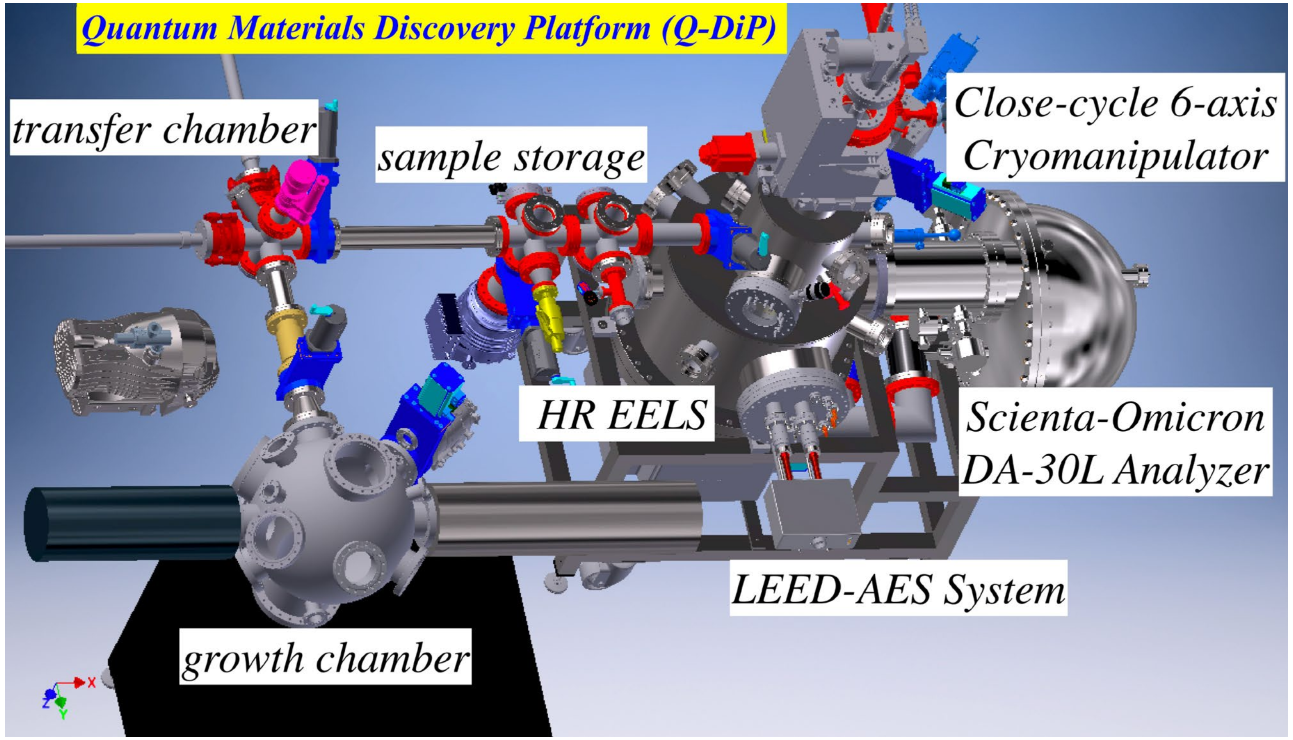
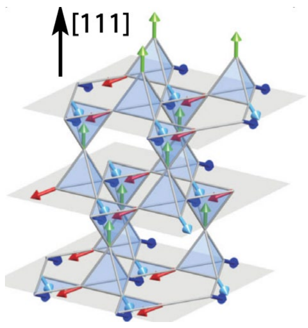
Our Setup in the Chakhalian Lab: Q-DiP

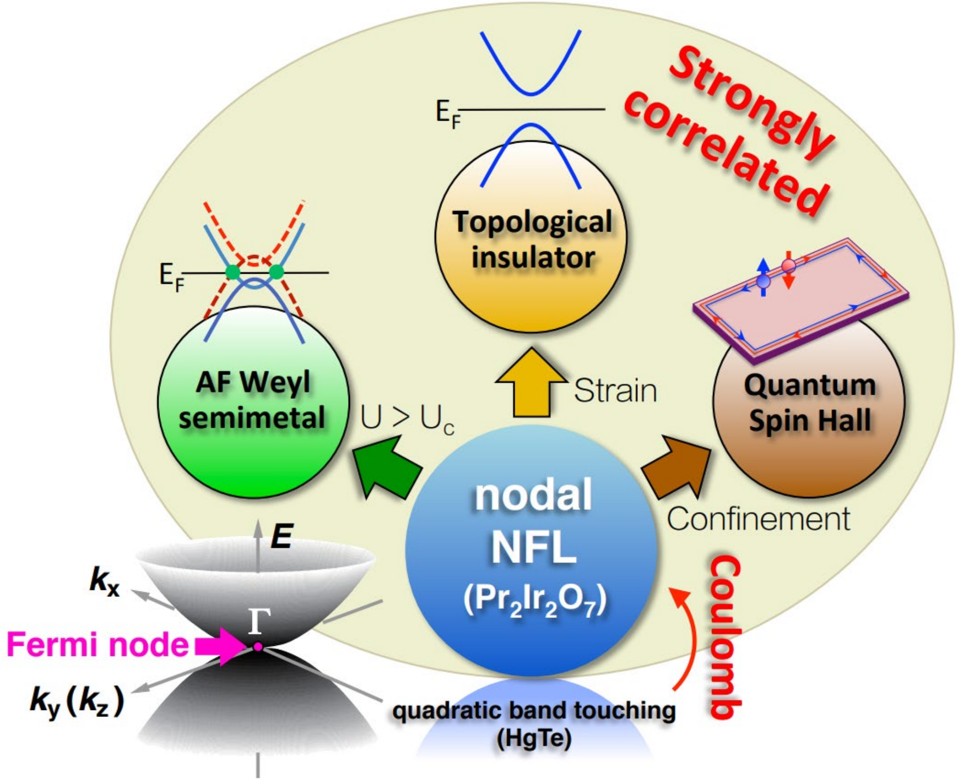


- Pyrochlore iridates are not easy to grow, but we can do it!
- *in-situ* ARPES allows us to grow and characterize without breaking vacuum
- Research plan: Measure effects of sample thickness, terminating layer

Conclusion

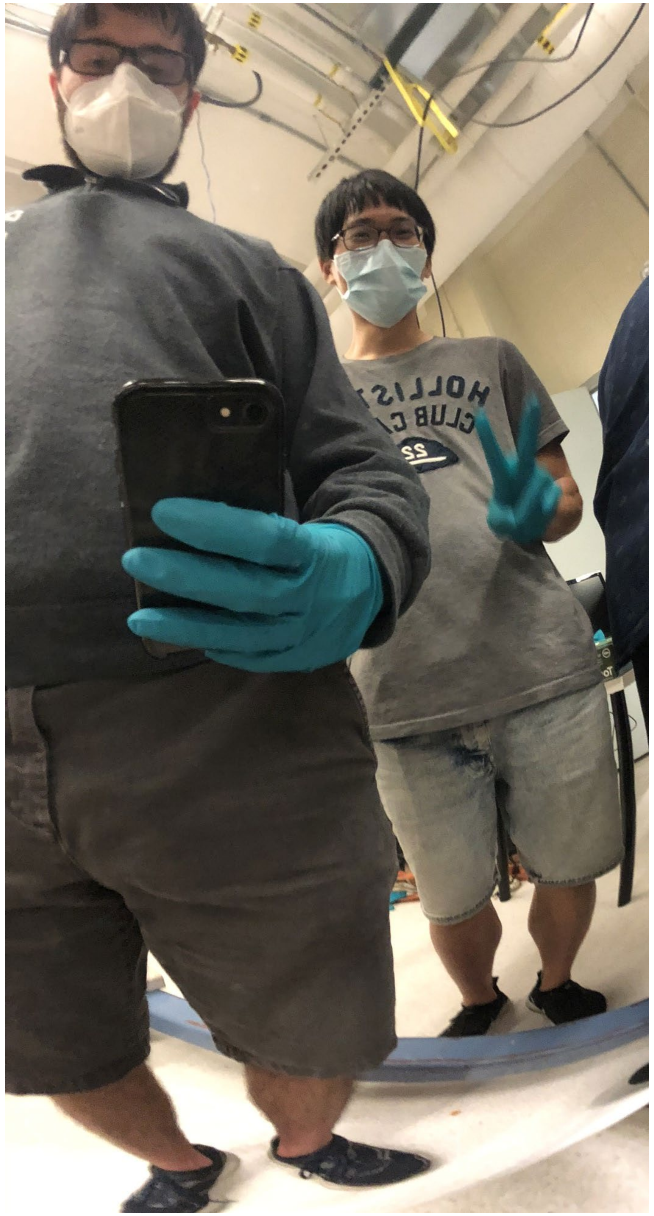
- Thin-film pyrochlore iridates can be manipulated to harbor many exotic phases
- ARPES is one of the primary tools for probing topological materials (like Weyl semimetals)
- Q-DiP can be used to grow and explore novel phases of thin-film iridates





[1], [8]

Thanks for listening!



Sources

[1] Yang, B.-J., & Nagaosa, N. (2014). *Emergent Topological Phenomena in Thin Films of Pyrochlore Iridates. Physical Review Letters, 112(24).*

[2] Jak Chakhalian, Xiaoran Liu, and Gregory A. Fiete. Strongly correlated and topological states in [111] grown transition metal oxide thin lms and heterostructures. APL Materials, page 050904, 2020.

[3] Simon Trebst. Kitaev Materials. Institute for Theoretical Physics.

[4] Binghai Yan and Claudia Felser. Topological Materials: Weyl Semimetals. Annual Review of Condensed Matter Physics 2017 8:1, 337-354

[5] Sun, Y., Wu, S.-C., & Yan, B. (2015). *Topological surface states and Fermi arcs of the noncentrosymmetric Weyl semimetals TaAs, TaP, NbAs, and NbP. Physical Review B, 92(11).* doi:10.1103/physrevb.92.115428

[6] M. Nakayama, Takeshi Kondo, Z. Tian, J. J. Ishikawa, M. Halim, C. Bareille, W. Malaeb, K. Kuroda, T. Tomita, S. Ideta, K. Tanaka, M. Matsunami, S. Kimura, N. Inami, K. Ono, H. Kumigashira, L. Balents, S. Nakatsuji, and S. Shin. Slater to mott crossover in the metal to insulator transition of nd2ir2o7. Phys. Rev. Lett., 117:056403, Jul 2016.

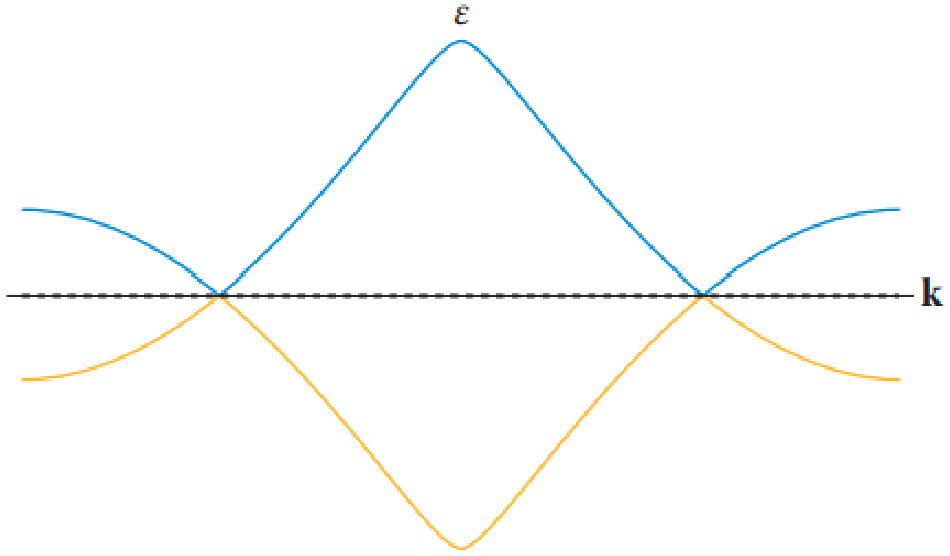
[7] Wan, X., Turner, A. M., Vishwanath, A., & Savrasov, S. Y. (2011). *Topological semimetal and Fermi-arc surface states in the electronic structure of pyrochlore iridates. Physical Review B, 83(20).* doi:10.1103/physrevb.83.205101

[8] Nakayama M. Chen R. et al. Kondo, T. Quadratic fermi node in a 3d strongly correlated semimetal. Nature Communications, page 10042, 2015.

Weyl points

- Monopoles in momentum space
- Topologically-protected band crossings
- 3D Hamiltonian with band crossing at $\boldsymbol{k} = \boldsymbol{k_0}$

$$H(k) = \epsilon_0\sigma_0 \pm \hbar v(\boldsymbol{k} - \boldsymbol{k_0}) \cdot \boldsymbol{\sigma}$$



- Consider perturbation $m\sigma_z$:

$$H'(k) = \epsilon_0\sigma_0 \pm \hbar v\boldsymbol{k} \cdot \boldsymbol{\sigma} + m\sigma_z$$

Takeaway: cannot remove this point with perturbation!