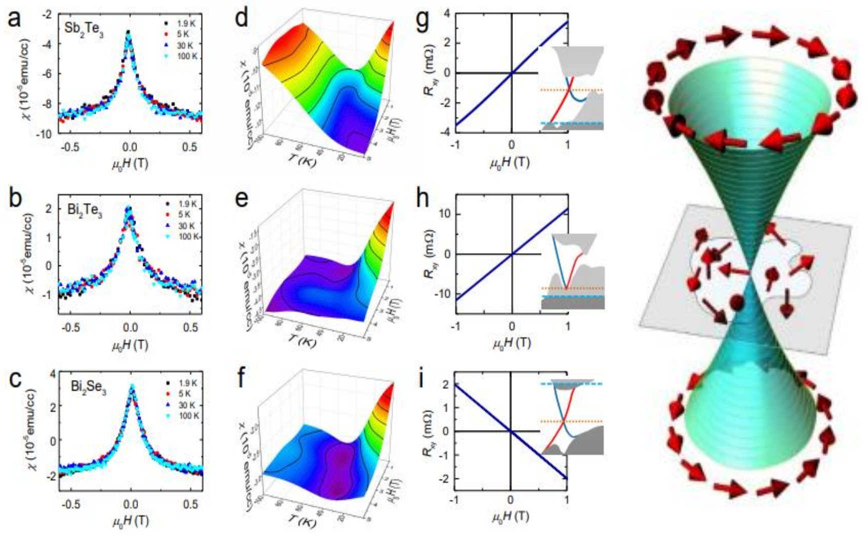
The singularity paramagnetic peak of $Bi_{0.3}Sb_{1.7}Te_3$ with *p*-type surface state

Shiu-Ming Huang[1,4,5*] , Pin-Cing Wang[1] , Pin-Cyuan Chen[1] , Jai-Long Hong[1] , Cheng-Maw Cheng[2] , Hao-Lun Jian[3] , You-Jhih Yan[3] , Shih-Hsun Yu[3] and Mitch M. C. Chou[3,4,5]

1 Department of Physics, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan.
2 National Synchrotron Radiation Research Center, Hsin-Chiu 80076, Taiwan.
3 Department of Materials and Optoelectronic Science, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan.
4 Taiwan Consortium of Emergent Crystalline Materials, TCECM, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan.
5 Center of Crystal Research, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan.

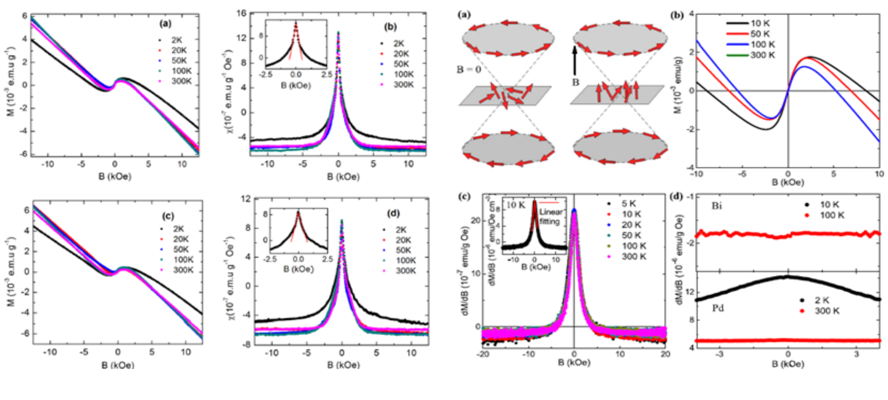
Background

- The temperature-independent susceptibility peaks are observed in various kinds of topological insulators. This characteristic is explained by the topological spin texture of surface state.



L. Zhao et. al., Nature Material 13, 580 (2014)

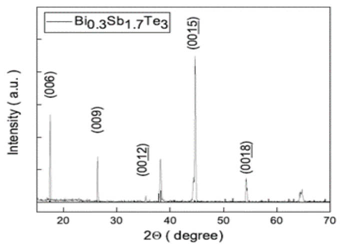
- The Dirac-type Hamiltonian describes the spin-momentum locking effect on the topological insulator surface state. The related spin texture at the upper and lower Dirac cone is in different directions.
- This particular spin texture suggests that carriers at the Dirac point do not have any preferred orientation and are free to align along with the external magnetic field. These freely oriented spins at the Dirac point are predicted to generate a paramagnetic peak in the susceptibility peak.
- Similar results and conclusions are reported in many topological materials, and all follows the same model to explain this behavior.
  1. Sci. Rep. 7, 40327 (2017), $ZrTe_5$ Dirac semi-metal.
  2. Sci. Rep. 7, 6321 (2017), LaBi Topological semi-metal .
  3. Sci. Rep. 7, 4883 (2017), $Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$ topological insulator .
  4. Phys. Rev. B 97, 205130 (2018), MoS_2 semi-metal.
  5. Phys. Rev. B 96, 245138 (2017), LaSbTe topological insulator.



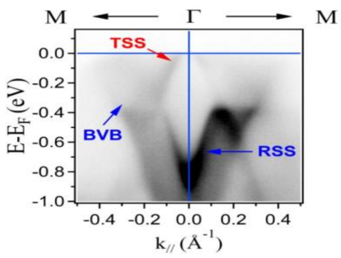
$Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$ topological insulator LaBi topological semi-metal

- Based on this model, these susceptibility peaks should be observed in the material with an *n*-type topological surface state. (With fermi level higher than Dirac point.)
- Without the Dirac point, the carrier spins should not align freely and there should be no susceptibility peaks.
- Fermi level is sensitive to materials and fabrication conditions. However, there is no evidence to support the claim that the Fermi level is above the surface state Dirac point in all these reports.
- To examine this mechanism, the study of magnetization was performed in $Bi_{0.3}Sb_{1.7}Te_3$ topological insulator with *p*-type surface state.

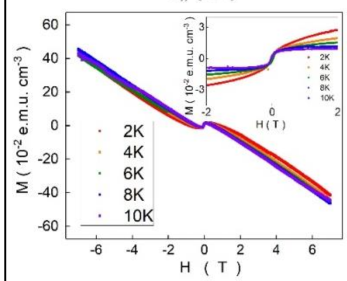
Result and Discussion



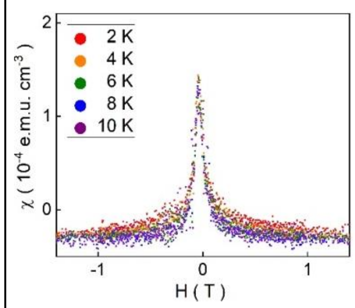
- The XRD spectrum reveals sharp peaks which supports that the $Bi_{0.3}Sb_{1.7}Te_3$ crystal is highly single-crystallized.



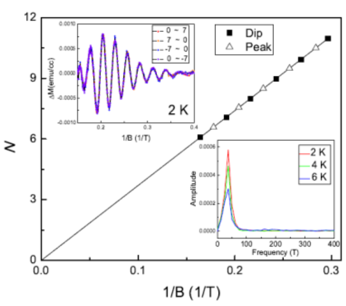
- The ARPES shows that the Fermi level is roughly 80 meV below the Dirac point.



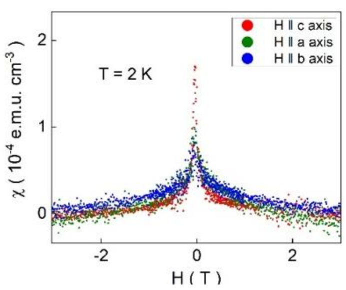
- The magnetization moment as a function of magnetic fields is shown here. There is a paramagnetic to diamagnetic crossover transition with an increasing magnetic field. The inset shows the magnetization moment after subtracting the linear field-dependent diamagnetism contribution as a function of the magnetic fields.



- The susceptibility as a function of magnetic fields from 2 to 10 K is presented here. All data collapse onto a single curve. This behavior is the same as all previous reports.
- But ARPES shows that there are no Dirac points in our single crystal. Following previous reports, there should be no susceptibility peaks in our system.
- This result strongly suggests that previous works should be completely modified.



- The extracted Fermi wavevector from the dHvA oscillations is consist of the ARPES result, and the Fermi wavevector is the same in different magnetic field sweeping directions and temperatures.
- The landau fan diagram supports these dHvA oscillations that come from the topological surface state.



- The measured magnetic field-dependent susceptibility in three orthogonal directions at 2 K is shown here. It exhibits different peak maxima at zero magnetic fields which implies that observed paramagnetic peaks should not originate from randomly and uniformly distributed ferromagnetic elements.

Conclusions:

- Our experiment reveals paramagnetic susceptibility peaks that collapse onto a single curve which is independent of temperatures.
- The ARPES reveals that the Fermi level is below the Dirac point, and the Fermi wavevector extracted from the ARPES is consistent with the determined value in the dHvA oscillations.
- These results support that the observed paramagnetic susceptibility peaks should not originate from the free-aligned spin texture at the Dirac point.