中国物理学会 Chinese Physical Society

IOP Institute of Physics

兰州大学物理科学与技术学院 School of Physical Science and Technology, Lanzhou University

CPS FALL MEETING 2020

Virtual CPS-IOP Joint Symposium

Topological Materials, Physics and Devices

HUAWEI

Quantum Design CHINA

中船鹏力超低温

SPECS-TII

Beijing, China

Sep. 18-20, 2020

CONTENTS

Welcome Message

Introduction to the 2020 Fall Meeting of the Chinese Physical Society

The CPS Fall Meeting was initiated in 1999, and has been held in every September since then. During last 20 years, we witnessed its rapid growth from about 300 participants in 1999 to over 5500 in 2019. It is one of the most important academic occasions for Chinese physicists. Since 2020, we will cosponsor with Institute of Physics, United Kingdom to establish a joint session "Topological Materials, Physics and Devices". This session will be held on 18-20 September, 2020 in Beijing, China.

Local Coordinator:

Prof. Xian-Gang Wan (Nanjing University, China)

International Coordinator:

Dr. Tim Smith (IOP Publishing, UK)

Live Link:

http://www.cps-net.org.cn/topological/video

Invited Speakers

Carlo Beenakker, Leiden University, The Netherlands

Title: Magnetic breakdown spectrum of a Kramers-Weyl semimetal

Bogdan A. Bernevig, Princeton University, USA

Title: Topology in Magnetic Materials and Engineered Devices

Shuguang Cheng, Northwest University, China

Title: Transport studies of topological interface states in low dimensional systems

Xi Dai, The Hong Kong University of Science and Technology, China

Title: Pseudo Landau level, orbital magnetism and quantum anomalous Hall effect in twisted graphene systems

Hong Ding, Institute of Physics, CAS, China

Title: Topological superconductivity and Majorana zero mode in iron-based superconductors

Jianwen Dong, Sun Yat-sen University, China

Title: Topological photonic crystals and their applications in nanophotonics

Claudia Felser, Max Planck Institute for Chemical Physics of Solids, Germany

Title: Magnetic Weyl Semimetals

Cheng He, Nanjing University, China

Title: Acoustic analogues of topological insulators

Ke He, Tsinghua University, China

Title: Intrinsic Magnetic Topological Insulator $MnBi_2Te_4$: A Road to High Temperature Quantum Anomalous Hall effect

David Hsieh, California Institute of Technology, USA

Title: Possible topological superconductor precursor phases uncovered by nonlinear optics

Jinfeng Jia, Shanghai Jiao Tong University, China

Title: Majorana zero mode for topological quantum computing

Eun-Ah Kim, Cornell University, USA

Title: 2D topological superconductors

Phil King, University of St Andrews, UK

Title: Bulk and Surface Dirac and Weyl States in Transition-Metal Dichalcogenides and NbGeSb

Alessandra Lanzara, UC Berkeley, USA

Title: Switchable spin states in topological insulators

Chunyin Qiu, Wuhan University, China

Title: Topological States in Sonic Crystals

Paolo Radaelli, Oxford University, UK

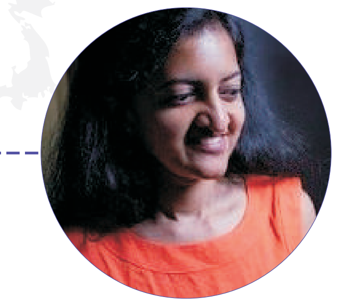
Title: Magnetism, the Movie: RT Half-skyrmions and Bimerons in a-Fe_2O_3 via the Kibble-Zurek mechanism

Leslie Schoop, Princeton University, USA

Title: From chemical bonds to topology

Suchitra Sebastian, Cambridge University, UK

Title: Bulk quantum oscillations in bulk topological insulators



Ashvin Vishwanath, Harvard University, USA

Title: Topology and Superconductivity from Electron Correlations in Magic Angle Graphene

Jian Wang, Peking University, China

Title: High-Chern-Number and High-Temperature Quantum Hall Effect without Landau Levels

Zhong Wang, Tsinghua University, China

Title: Non-Bloch band theory: Applications to non-Hermitian topology and nonreciprocal amplification

Yong Xu, Tsinghua University, China

Title: Seeking high-temperature quantum anomalous Hall insulators

Hongming Weng, Institute of Physics, CAS, China

Title: Layer construction of topological crystalline insulator LaSbTe

Yugui Yao, Beijing Institute of Technology, China

Title: Topological magneto-optical effect and its quantization in noncoplanar antiferromagnets

Xincheng Xie, Peking University, China

Title: 3D quantum Hall effect in topological semimetals

Haijun Zhang, Nanjing University, China

Title: Engineered dynamical axion field in quantized axion insulator $MnBi_2Te_4$ films

Faxian Xiu, Fudan University, China

Title: Fermi arc transport and quantum Hall effect in topological Semimetals

Liyuan Zhang, Southern University of Science and Technology, China

Title: Quantum plateau phenomena in 3D system

Schedule

Friday, Sep. 18, 2020 8:20-17:00 Venue: Room M234, Building M, Institute of Physics, CAS			
Chair: Xian-Gang Wan (Nanjing University)			
8:20-8:30	Opening Speech Jie Zhang (President of the Chinese Physical Society) Paul Hardaker (CEO of the Institute of Physics, UK)		
Beijing Time	Speaker	Title	Abstract
8:30-9:00	Xincheng Xie (Peking University, China)	3D quantum Hall effect in topological semimetals	Page13
9:00-9:30	Ashvin Vishwanath (Harvard University, USA)	Topology and Superconductivity from Electron Correlations in Magic Angle Graphene	Page14
Chair: Haizhou Lu (Southern University of Science and Technology)			
9:30-10:00	Xi Dai (The Hong Kong University of Science and Technology, China)	Pseudo Landau level, orbital magnetism and quantum anomalous Hall effect in twisted graphene systems	Page15
10:00-10:30	Eun-Ah Kim (Cornell University, USA)	2D topological superconductors	Page16
10:30-11:00	Jinfeng Jia (Shanghai Jiao Tong University, China)	Majorana zero mode for topological quantum computing	Page17
11:30-12:30	Lunch at the 3rd floor of Wuke Hotel		
Chair: Xi Dai (The Hong Kong University of Science and Technology)			
15:00-15:30	Hongming Weng (Institute of Physics, CAS, China)	Layer construction of topological crystalline insulator LaSbTe	Page18
15:30-16:00	Carlo Beenakker (Leiden University, The Netherlands)	Magnetic breakdown spectrum of a Kramers-Weyl semimetal	Page19
16:00-16:30	Hong Ding (Institute of Physics, CAS, China)	Topological superconductivity and Majorana zero mode in iron-based superconductors	Page20
16:30-17:00	Suchitra Sebastian (Cambridge University, UK)	Bulk quantum oscillations in bulk topological insulators	Page21
17:30-18:30	Dinner at the 3rd floor of Wuke Hotel		

Saturday, Sep. 19, 2020 8:30-21:30 Venue: Room M234, Building M, Institute of Physics, CAS			
Chair: Zhong Wang (Tsinghua University)			
Beijing Time	Speaker	Title	Abstract
8:30-9:00	David Hsieh (California Institute of Technology, USA)	Possible topological superconductor precursor phases uncovered by nonlinear optics	Page22
9:00-9:30	Ke He (Tsinghua University, China)	Intrinsic Magnetic Topological Insulator $MnBi_2Te_4$: A Road to High Temperature Quantum Anomalous Hall effect	Page23
9:30-10:00	Jian Wang (Peking University, China)	High-Chern-Number and High-Temperature Quantum Hall Effect without Landau Levels	Page24
10:00-10:30	Yong Xu (Tsinghua University, China)	Seeking high-temperature quantum anomalous Hall insulators	Page25
10:30-11:00	Haijun Zhang (Nanjing University, China)	Engineered dynamical axion field in quantized axion insulator $MnBi_2Te_4$ films	Page26
11:30-12:30	Lunch at the 3rd floor of Wuke Hotel		
Chair: Phil King (University of St. Andrews)			
15:00-15:30	Claudia Felser (Max Planck Institute for Chemical Physics of Solids, Germany)	Magnetic Weyl Semimetals	Page27
15:30-16:00	Zhong Wang (Tsinghua University, China)	Non-Bloch band theory: Applications to non-Hermitian topology and nonreciprocal amplification	Page28
16:00-16:30	Liyuan Zhang (Southern University of Science and Technology, China)	Quantum plateau phenomena in 3D system	Page29
16:30-17:00	Shuguang Cheng (Northwest University, China)	Transport studies of topological interface states in low dimensional systems	Page30
17:30-18:30	Dinner at the 3rd floor of Wuke Hotel		
Chair: Suchitra Sebastian (Cambridge University)			
20:00-20:30	Paolo Radaelli (Oxford University, UK)	Magnetism, the Movie: RT Half-skyrmions and Bimerons in a-Fe_2O_3 via the Kibble-Zurek mechanism	Page31
20:30-21:00	Faxian Xiu (Fudan University, China)	Fermi arc transport and quantum Hall effect in topological Semimetals	Page32
21:00-21:30	Leslie Schoop (Princeton University, USA)	From chemical bonds to topology	Page33

Sunday, Sep. 20, 2020 15:00-21:30 Venue: Room M234, Building M, Institute of Physics, CAS			
Chair: Ling Lu (Institute of Physics, CAS)			
Beijing Time	Speaker	Title	Abstract
15:00-15:30	Alessandra Lanzara (UC Berkeley, USA)	Switchable spin states in topological insulators	Page34
15:30-16:00	Jianwen Dong (Sun Yat-sen University, China)	Topological photonic crystals and their applications in nanophotonics	Page35
16:00-16:30	Chunyin Qiu (Wuhan University, China)	Topological States in Sonic Crystals	Page36
16:30-17:00	Cheng He (Nanjing University, China)	Acoustic analogues of topological insulators	Page37
17:30-18:30	Dinner at the 3rd floor of Wuke Hotel		
Chair: Yong Xu (Tsinghua University)			
20:00-20:30	Bogdan A. Bernevig (Princeton University, USA)	Topology in Magnetic Materials and Engineered Devices	Page38
20:30-21:00	Yugui Yao (Beijing Institute of Technology, China)	Topological magneto-optical effect and its quantization in noncoplanar antiferromagnets	Page39
21:00-21:30	Phil King (University of St Andrews, UK)	Bulk and Surface Dirac and Weyl States in Transition-Metal Dichalcogenides and NbGeSb	Page40

Time Zone Comparison				
China Standard Time (Beijing)	08:00	10:00	15:00	20:00
British Summer Time (London)	01:00	03:00	08:00	13:00
Central European Summer Time	02:00	04:00	09:00	14:00
Eastern Daylight Time (New York)	20:00 (The day before)	22:00 (The day before)	03:00	08:00
Pacific Daylight Time (Los Angeles)	17:00 (The day before)	19:00 (The day before)	00:00	05:00

Abstracts

Title: 3D quantum Hall effect in topological semimetals

Author: Xin-cheng Xie

Address: Peking University, China

Abstract:

We investigate the 3D quantum Hall effect in Weyl semimetals and elucidate a global picture of the edge states. The edge states hosting 3D quantum Hall effect are combinations of Fermi arcs and chiral Landau bands dispersing along the magnetic field direction. The Hall conductance shows quantized plateaus with the variance of the magnetic field when the Fermi level is at the Weyl node. However, the chiral Landau bands can change the spatial distribution of the edge states, especially under a tilted magnetic field, and the resulting edge states lead to distinctive Hall transport phenomena. Our work uncovers the novel edge-state nature of the 3D quantum Hall effect in Weyl semimetals.

Title: Topology and Superconductivity from Electron Correlations in Magic Angle Graphene
Author: Ashvin Vishwanath
Address: Harvard University, USA

Abstract:

We derive an effective theory for strongly interacting electrons in the flat bands of magic angle graphene, which is shown to take the form of a topological sigma-model. The model is characterized by a small number of physical parameters, and is found to predict a sequence of flavor ordered states near integer fillings. Moreover, topological textures in this sigma-model are shown to bind electric charge. This remarkable feature allows us to study charge doping within the sigma mode itself, and leads to a novel `all electronic' pairing mechanism, even in the regime where Coulomb repulsion dominates. We discuss the potential applicability of this mechanism to explain the superconductivity observed in magic angle graphene as well as extract guidelines for creating other platforms where similar physics should emerge.

Title: Pseudo Landau level, orbital magnetism and quantum anomalous Hall effect in twisted graphene systems
Author: Xi Dai
Address: The Hong Kong University of Science and Technology, China

Abstract:

Moir\'e graphene systems have drawn significant attention recently due to various exotic phenomena observed in these systems including the correlated insulating states, unconventional superconductivity, and quantum anomalous Hall effect. All these phenomena are intimately related to the valley-spin degenerate, and topologically nontrivial flat bands in the moir\'e graphene systems. When time-reversal symmetry is broken spontaneously, such flavor degenerate topological flat bands exhibit unconventional orbital magnetism which are associated with real-space current-loop patterns on the moir\'e length scale. In this review, we start by retrospecting the key experimental progress about the correlated insulating states and the quantum anomalous Hall phenomena. In order to understand these phenomena, we continue discussing the topological properties of the moir\'e flat bands, as well as the transport and optical properties of the moir\'e orbital magnetic states. In the end, we discuss the latest theoretical progress in the understanding of the correlated insulating and quantum anomalous Hall phenomena from the perspective of spontaneous symmetry breaking.

Title: 2D topological superconductors

Author: Eun-Ah Kim
Address: Cornell University, USA

Abstract:

Title: Majorana zero mode for topological quantum computing

Author: Jinfeng Jia
Address: Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China

Abstract:

Majorana zero mode (MZM) can be used in fault-tolerant quantum computation relying on their non-Abelian braiding statistics, therefore, lots of efforts have been made to find them. Signatures of the MZMs have been reported as zero energy modes in various systems. As predicted, MZM in the vortex of topological superconductor appears as a zero energy mode with a cone like spatial distribution. Also, MZM can induce spin selective Andreev reflection (SSAR), a novel magnetic property which can be used to detect the MZMs. Here, I will show you that the $Bi_2Te_3/NbSe_2$ hetero-structure is an artificial topological superconductor and all the three features are observed for the MZMs inside the vortices on the $Bi_2Te_3/NbSe_2$. Especially, by using spin-polarized scanning tunneling microscopy/ spectroscopy, we observed the spin dependent tunneling effect, which is a direct evidence for the SSAR from MZMs, and fully supported by theoretical analyses. More importantly, all evidences are self-consistent. Our work provides definitive evidences of MZMs and will stimulate the research on their novel physical properties, hence a step towards their statistics and application in quantum computing. A novel way to control the motion of MZM with electronic field is also proposed. In the second part, I will show you the first direct evidence of a Bogoliubov Fermi surface predicted by BCS theory. Also, we can see that the Bogoliubov Fermi surface can be controlled by the direction and magnitude of the applied in-plan magnetic field.

[1] Mei-Xiao Wang, et al., Science 336, 52-55 (2012)
[2] J.P. Xu, et al., Phys. Rev. Lett. 112, 217001 (2014)
[3] J.P. Xu, et al., Phys. Rev. Lett. 114, 017001 (2015)
[4] H.H. Sun, et al., Phys. Rev. Lett. 116, 257003 (2016)
[5] H.H. Sun, Jin-Feng Jia, NPJ Quan. Mater. 2, 34 (2017)

Title: Layer Construction of Topological Crystalline Insulator LaSbTe

Author: Hongming Weng

Address: Institute of Physics, Chinese Academy of Sciences, China

Abstract:

Symmetry protected topology has been largely extended from time-reversal symmetry to crystalline symmetries [1]. Based on the topological quantum chemistry theory [2] or symmetry-based indicators [3], the band topology has been related with the localized atomic orbitals in chemistry picture, and the topological nontrivial state can be identified from the trivial atomic insulators by examining their symmetry data. In addition to the well-known topological crystalline insulators (TCIs) protected by mirror or glide symmetry, those protected by rotation, screw, inversion and S4 symmetries have also been found [4, 5, 6] based on layer construction (LC) scheme, where a TCI can be a simple product state of decoupled two-dimensional topological insulators (TIs) decorating the lattice space. There have been topological materials databases [7, 8, 9] to list these TCI candidates. In this talk, based on first-principles calculations we have revealed that both the tetragonal LaSbTe (t-LaSbTe) and the orthorhombic LaSbTe (o-LaSbTe) can be looked as a stacking of 2D TIs in each lattice space. The structural phase transition from t-LaSbTe to o-LaSbTe due to soft phonon modes demonstrates how the real space change can lead to the modification of topological states. Their symmetry-based indicators and topological invariants have been analyzed based on LC. We propose that LaSbTe is an ideal paradigm perfectly demonstrating the LC scheme, which bridges the crystal structures in real space to the band topology in momentum space.

[1] Chiu, C.-K., Teo, J. C., Schnyder, A. P. & Ryu, S. Classification of topological quantum matter with symmetries. Reviews of Modern Physics 88, 035005 (2016).
[2] Bradlyn, B. et al. Topological quantum chemistry. Nature 547, 298 EP – (2017).
[3] Po, H. C., Vishwanath, A. & Watanabe, H. Symmetry-based indicators of band topology in the 230 space groups. Nature Communications 8, 50 (2017).
[4] Song, Z., Fang, Z. & Fang, C. (d − 2)-dimensional edge states of rotation symmetry protected topological states. Phys. Rev. Lett. 119, 246402 (2017).
[5] Song, Z., Zhang, T.-T., Fang, Z. & Fang, C. Quantitative mappings between symmetry and topology in solids. Nature Communications 9, 3530 (2018)
[6] Tang, F., Po, H.-C., Vishwanath, A and Wan, X.-G. Efficient topological materials discovery using symmetry indicators. Nat. Phys. 15, 470 (2010)
[7] Zhang, T., Song, Z., Huang, H., He, Y., Fang, Z., Weng, H. & Fang, C. Catalogue of Topological Electronic Materials. Nature 566, 475 (2019)
[8] Vergniory, M. G., Elcoro, L., Felser, C., Bernevig, B. A. & Wang. Z. A complete catalogue of high-quality topological materials. Nature 566, 480 (2019)
[9] Tang, F., Po, H. C., Vishwanath, A. & Wan, X. Comprehensive search for topological materials using symmetry indicators. Nature 566, 486 (2019)

Title: Magnetic breakdown spectrum of a Kramers-Weyl semimetal

Author: Carlo Beenakker

Address: Instituut-Lorentz, Leiden University, The Netherlands

Abstract:

We calculate the Landau levels of a Kramers-Weyl semimetal thin slab in a perpendicular magnetic field B. The coupling of Fermi arcs on opposite surfaces broadens the Landau levels with a band width that oscillates periodically in 1/B. We interpret the spectrum in terms of a one-dimensional superlattice induced by magnetic breakdown at Weyl points. The band width oscillations may be observed as 1/B-periodic magnetoconductance oscillations, at weaker fields and higher temperatures than the Shubnikov-de Haas oscillations due to Landau level quantization. No such spectrum appears in a generic Weyl semimetal, the Kramers degeneracy at time-reversally invariant momenta is essential.

With G. Lemut, A. Donís Vela, M. J. Pacholski, and J. Tworzydło, to appear in New Journal of Physics (arXiv:2004.06406)

Title: Topological superconductivity and Majorana zero mode in iron-based superconductors
Author: Hong Ding
Address: Institute of Physics, CAS, China

Abstract:

In this talk I will report our recent discoveries of topological superconductivity and Majorana zero mode in iron-based superconductors. We have observed a superconducting topological surface state of Fe(Te, Se) with Tc ~ 14.5K by using low-temperature ARPES [1], and a pristine Majorana zero mode (MZM) inside a vortex core of this material by using low-temperature STM [2]. We have also observed a half-integer level shift of vortex bound states [3] and nearly quantized Majorana conductance [4] in this material, which are hallmarks of MZMs. In addition, we have also found that most of Fe-based superconductors [5], including monolayer Fe(Te, Se)/STO [6], have similar topological electronic structures. One of them, $CaKFe_4As_4$, an Fe-As bilayer superconductor (Tc ~ 35K), is found to possess MZM and other bound states that can be well reproduced by a simple theoretical model [7]. Our observations offer a new, robust platform for realizing and manipulating MZMs, which can be used for quantum computing at a relatively high temperature.

[1] Peng Zhang et al., Science 360, 182 (2018)
[2] Dongfei Wang et al., Science 362, 334 (2018)
[3] Lingyuan Kong et al., Nature Physics 15, 1181 (2019)
[4] Shiyu Zhu et al., Science 367, 189 (2020)
[5] Peng Zhang et al., Nature Physics 15, 41 (2019)
[6] Xun Shi et al., Science Bulletin 62, 503 (2017)
[7] Wenyao Liu et al., arXiv:1907.00904

Title: Bulk quantum oscillations in bulk topological insulators
Author: Suchitra Sebastian
Address: Cambridge University, UK

Abstract:

Title: Possible topological superconductor precursor phases uncovered by nonlinear optics

Author: David Hsieh

Address: Department of Physics, California Institute of Technology, Pasadena CA 91125, USA

Abstract:

In the presence of strong interactions, the fluid of mobile electrons in a metal can spontaneously break the point group symmetries of its underlying lattice, forming an electronic analogue of a classical liquid crystal. The experimental discovery of 2D electronic liquid crystals (ELCs) was first made nearly 20 years ago in semiconductor heterostructures and has since been reported in many other systems including the copper- and iron-based high-temperature superconductors. Recently a new class of 3D ELCs with spontaneously broken inversion symmetry was predicted to arise in correlated metals with strong spin-orbit coupling, which are proposed to be precursors to topological superconducting phases. In this talk, I will discuss our search for 3D ELCs in the non-centrosymmetric metals $LiOsO_3$ and $Cd_2Re_2O_7$ using ultrafast and nonlinear optical spectroscopy.

Title: Intrinsic Magnetic Topological Insulator $MnBi_2Te_4$: A Road to High Temperature Quantum Anomalous Hall effect

Author: Ke He

Address:

1 State Key Laboratory of Low-Dimensional Quantum Physics, Department of Physics, Tsinghua University, Beijing 100084, China

2 Frontier Science Center for Quantum Information, Beijing 100084, China

3 Beijing Institute of Quantum Information Science, Beijing 100193, China

Abstract:

The quantum anomalous Hall effect usually requires an ultralow temperature below 100 mK to exhibit in magnetically doped topological insulator. It is mainly caused by the strong inhomogeneity in the chemical potential and exchange energy in magnetically doped topological insulators induced by the randomly scattered magnetic impurities. Elevating the temperature to realize the quantum anomalous Hall effect to above 77 K or higher is crucial for its practical applications in electronics. An ideal magnetic topological insulator for this purpose is an intrinsic one, namely a stoichiometric compound, including orderly arranged magnetic atoms, which has a ferromagnetic ground state while becomes a TI when the TRS recovers above Curie temperature. In this talk I will introduce the recent research progress on $MnBi_2Te_4$-family intrinsic magnetic topological insulators, trying to present a simple picture to understand their properties and topological properties and a concise guide to engineer them for the quantum anomalous Hall effect at higher temperature.

Title: High-Chern-Number and High-Temperature Quantum Hall Effect without Landau Levels
Author: Jian Wang
Address: International Center for Quantum Materials, School of Physics, Peking University, Beijing, China

Abstract:

The quantum Hall effect (QHE) without Landau levels (LLs) has become a long-pursuit research topic since the QHE was discovered around 40 years ago. Previous theoretical proposals and experiments based on two-dimensional (2D) topological systems with time-reversal symmetry broken have revealed the QHE without LLs with Chern number |C|=1 at ultralow temperatures. Now the key issues of the QHE without LLs are how to increase the working temperature and realize high Chern number with more dissipationless chiral edge states (|C|>1) for emerging physics and low-dissipation electronics. We discovered the high-Chern-number (|C|=2) QHE without LLs in nine-septuple-layer and ten-septuple-layer magnetic $MnBi_2Te_4$ devices and |C|=1 Chern insulator state in seven-septuple-layer and eight-septuple-layer devices displaying nearly quantized Hall resistance plateau at record-high temperatures [1]. The thickness-dependent topological quantum phase transition from |C|=2 to |C|=1 is uncovered. To our knowledge, this is the first work to report high-Chern-number QHE without LLs above the liquid helium temperature and this is also the first time that the nearly quantized Hall resistance plateau is detected at high temperatures of tens of Kelvin for QHE without LLs.

[1] Jun Ge, Yanzhao Liu, Jiaheng Li, Hao Li, Tianchuang Luo, Yang Wu, Yong Xu, Jian Wang, National Science Review 7, 1280 (2020). Highlighted by the Editors' Choice of Science with a title of "Tuning the Chern number" (Science 368, 962(2020)

Title: Seeking high-temperature quantum anomalous Hall insulators
Author: Yong Xu
Address: Department of Physics, Tsinghua University, China
RIKEN Center for Emergent Matter Science (CEMS), Japan

Abstract:

Quantum anomalous Hall (QAH) insulator is the key material to explore emergent topological quantum effects, but its ultralow working temperature limits experiments. From the material point of view, the QAH insulator is a specific type of two-dimensional (2D) ferromagnetic semiconductor featured by a topological energy gap opened by the spin-orbit coupling (SOC). In order to achieve high-temperature QAH state, both the ferromagnetic coupling and SOC strength must be appreciable. However, high-temperature ferromagnetic semiconductors are rare in nature and none of them features a nontrivial topology. In this talk, I will present four different physical scenarios to realize QAH states through introducing quantum confinement effects into distinct kinds of magnetic topological states in 3D, including (i) antiferromagnetic topological insulator, (ii) ferromagnetic Weyl semimetal, (iii) high-order ferromagnetic topological insulator, and (iv) 3D QAH insulator. I will also show their material realizations, based on the recently found $MnBi_2Te_4$-family and LiFeSe-family materials [1-5]. Remarkable experimental progresses on the former materials have been achieved [6-10], whereas the theoretical prediction of room-temperature ferromagnetism and large QAH gap in the latter materials [5], which enables the realization of high-temperature QAH effect, is awaiting for experimental proof.

[1] J. Li, et al. Sci. Adv. 5, eaaw5685 (2019).
[2] J. Li, et al. Phys. Rev. B 100, 121103® (2019).
[3] S. Du, et al. Phys. Rev. Research 2, 022025® (2020).
[4] Z. Li, et al. Phys. Rev. B 102, 081107® (2020).
[5] Y. Li, et al. Phys. Rev. Lett. 125, 086401 (2020).
[6] Y. Gong, et al. Chin. Phys. Lett. 36, 076801 (2019).
[7] Y. Deng, et al. Science 367, 895 (2020).
[8] C. Liu, et al. Nature Mater. 19, 522 (2020).
[9] J. Ge, et al. Natl. Sci. Rev. nwaa089 (2020).
[10] C. Liu, et al. arXiv:2001.08401.

Title: Engineered dynamical axion field in quantized axion insulator $MnBi_2Te_4$ films

Author: Haijun Zhang

Address: Nanjing University, China

Abstract:

The dynamical axion field is a new state of quantum matter where the magnetoelectric response couples strongly to its low-energy magnetic fluctuations. It is fundamentally different from an axion insulator with a static quantized magnetoelectric response. The dynamical axion field exhibits many exotic phenomena such as axionic polariton and axion instability. However, these effects have not been experimentally confirmed due to the lack of proper topological magnetic materials. Recently, the antiferromagnetic topological insulator Mn-Bi-Te family materials attracted great attention. In this talk, we will briefly introduce the theoretical and experimental progress of Mn-Bi-Te family. Then, we will focus on how to design/realize dynamical axion field in Mn-Bi-Te family materials, and we also will talk about the topological definition for the dynamical axion insulators.

Title: Magnetic Weyl Semimetals

Author: Claudia Felser

Address: Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Abstract:

Topology a mathematical concept became recently a hot topic in condensed matter physics and materials science. One important criteria for the identification of the topological material is in the language of chemistry the inert pair effect of the s-electrons in heavy elements and the symmetry of the crystal structure [1]. Beside of Weyl and Dirac new fermions can be identified compounds via linear and quadratic 3-, 6- and 8- band crossings stabilized by space group symmetries [2]. In magnetic materials the Berry curvature and the classical AHE helps to identify interesting candidates. Magnetic Heusler compounds were already identified as Weyl semimetals such as Co2YZ [3-6] (Y=Ti, Mn; Z=Ge, Sn, Ga, Al). $Co_3Sn_2S_2$ is a 2D Weyl semimetal with edge states [7-9]. Transport data, ARPES and STM measurements will be discussed.

[1]Bradlyn et al., Nature 547 298, (2017)
[2]Bradlyn, et al., Science 353, aaf5037A (2016).
[3]Kübler and Felser, Europhys. Lett. 114, 47005 (2016)
[4]Wang, et al. Phys. Rev. Lett. 117, 236401 (2016)
[5]Chang et al., Scientific Reports 6, 38839 (2016)
[6]I. Belopolski, et al., Science 365, 1278 (2019)
[7]Liu, et al. Nature Physics 14, 1125 (2018)
[8]D. F. Liu, et al., Science 365, 1282 (2019)
[9]N. Morali, et al., Science 365, 1286 (2019)

Title: Non-Bloch band theory: Applications to non-Hermitian topology and nonreciprocal amplification

Author: Zhong Wang
Address: Institute for Advanced Study, Tsinghua University, Beijing, 100084, China

Abstract:

Effective Non-Hermitian Hamiltonian is a widely useful language for describing open systems. Intriguingly, non-Hermitian systems exhibit a unique bulk-boundary correspondence beyond the conventional framework of Bloch band theory. To predict the topological edge modes, topological invariants have to be defined in a generalized Brillouin zone rather than in the familiar one. We also show that the consequences of this revision of band theory are not limited to non-Hermitian topology. Among other results beyond topology, we show that the non-Bloch band theory has a natural application to the working of nonreciprocal amplification, a phenomenon that signals are amplified in a preferred propagation direction while suppressed in the reversed direction. Compact formulas for the gain and directionality of one-dimensional nonreciprocal amplifiers are obtained in the framework of non-Bloch band theory.

[1] Shunyu Yao, Zhong Wang, Edge states and topological invariants of non-Hermitian systems, Phys. Rev. Lett. 121, 086803 (2018)
[2] Lei Xiao, et al. Non-Hermitian bulk-boundary correspondence in quantum dynamics. Nat. Phys. 16, 761 (2020)
[3] Wen-Tan Xue, Ming-Rui Li, Yu-Min Hu, Fei Song, Zhong Wang, Non-Hermitian band theory of directional amplification, arXiv:2004.09529

Title: Quantum plateau phenomena in three dimensional systems

Author: Liyuan Zhang
Address: Department of Physics,Southern University of Science and Technology, 518055, China

Abstract:

The discovery of quantum Hall effect had greatly improved the understanding of the phase transitions and topological orders in two-dimensional systems. It is natural to ask whether there are similar phenomena that might occur in three-dimensional gas systems. However, the long-sought three-dimensional (3D) quantum Hall effect has not been well experimentally demonstrated in 3D gas system. Here we report an experimental observation of three-dimensional quantum Hall effect in zirconium Penta-telluride($ZrTe_5$) within a magnetic field B (<1.3T). We also discover that each Quantum Layer contributes $2e^2/h$ with a thickness of one Fermi wavelength λ_F in b direction. As further increasing magnetic field, the system has reached the Quantum Limit regime, where the resistance $\rho_{xx}(B)$ increases dramatically and displays Metal-Insulator transition behavior. With analyzing $\rho_{xx}(B)$ scaling plots, we confirm this Metal-Insulator transition is a many-body quantum topological phase transition. Our finding not only provides a new understanding of the interplay between 2D and 3D Landau quantization but also allows for the further exploration of the higher dimensional electronic gas system and exotic strongly corrected topological phase transitions. We also explored the thermoelectric properties of $ZrTe_5$, and found a "quantized" thermoelectric Hall conductivity at sufficiently high magnetic field (or extreme quantum limit). This plateau was explained as a signature of Dirac polaron in three-dimensional system.

[1] FD. Tang †, YF. Ren †, P P. Wang, R.D. Zhong, J . Schneeloch, , S. A. Yang*, K. Yang, P . A. Lee, G. Gu, ZH. Qiao*, and LY. Zhang*,"Three-dimensional quantum Hall effect and metal-insulator transition in ZrTe5", Nature 569, 537 (2019).
[2] Wenjie Zhang, Peipei Wang, Brian Skinner, Ran Bi, Vladyslav Kozii, Chang-Woo Cho, Ruidan Zhong, John Schneeloch, Dapeng Yu, Genda Gu, Liang Fu, Xiaosong Wu, Liyuan Zhang, "Observation of a thermoelectric Hall plateau in the extreme quantum limit" Nature Communication,11,1046, (2020).

Title: Transport studies of topological interface states in low dimensional systems

Author: Shu-guang Cheng
Address: Northwest University, China

Abstract:

Topological materials, characterized by the topology protected surface states or edge states, are attractive from both the scientific research aspect and the fabrication of dispassionless electronic devices. In this talk, the theoretical studies of transport properties of several types of topological interface states are discussed. i) The generation of valley polarized topological kink states in graphene systems; ii) How to distinguish and manipulate the valley polarized topological kink states; iii) Using topological kink states based on artificial graphene in two-dimensional electron gas, Majorana zero modes and their transport properties are discussed; iv) In wedge-shaped electron gas systems, bulk Landau level appears and induces peculiar transport characteristics.

[1] S. G. Cheng, J. Zhou, H. Jiang and Q.-F. Sun, New J. Phys. 18 103024 (2016).
[2] S. G. Cheng, H. W. Liu, H. Jiang, Q.-F. Sun, and X. C. Xie, Phys. Rev. Lett. 121, 156801 (2018).
[3] S. G. Cheng, J. Liu, H. Liu, H. Jiang, Q.-F. Sun, and X. C. Xie, Phys. Rev. B 101, 165420 (2020).
[4] S. G. Cheng, H. Jiang, Q.-F. Sun, and X. C. Xie, Phys. Rev. B 102, 075304 (2020).

Title: Magnetism, the Movie: RT Half-skyrmions and Bimerons in a-Fe_2O_3 via the Kibble-Zurek mechanism

Author: Paolo G. Radaelli
Address: Clarendon Laboratory, Department of Physics, University of Oxford, OX1 3PU, United Kingdom

Abstract:

IT technology experts agree that the next phase of Moore's law will be based on energy efficiency rather than transistor density. Indeed, the energy efficiency of CMOS devices is 5-6 orders of magnitude worse that than of the human brain, which is at least 3 orders of magnitude away from the ultimate physical limits. Quantum materials (QM) will be crucial to achieve the ambitious goal of 1-10 aJ/operation. A number of promising concepts have been proposed, many involving the creation and manipulation of real-space magnetic topological structures such as skyrmions in metallic ferromagnets. Antiferromagnetic analogues have recently come into intense focus, but their experimental realizations in natural systems were yet to emerge. Previously, we have speculated that topological structures such as vortices might emerge at the Néel temperature in simple antiferromagnets via the so-called Kibble-Zurek mechanism [1], initially proposed in the context of cosmology. Using linear and circular X-ray photoelectron emission microscopy (X-PEEM), we indeed observed vortices/antivortices in antiferromagnetic haematite (α-Fe_2O_3) epitaxial films, in which the primary whirling parameter is the staggered magnetization [2]. Ferromagnetic topological objects with the same vorticity and winding number as the α-Fe_2O_3 vortices were 'imprinted' onto an ultra-thin Co ferromagnetic over-layer by interfacial exchange. In this talk, I will present our more recent results on α-Fe_2O_3 [3]. By replacing Co with Pt, we manage to activate the so-called Morin first-order transition, which occurs in bulk α-Fe_2O_3 just below room temperature, and to tune it precisely by small amounts of Rh doping. Remarkably, the first-order analogue of the Kibble-Zurek mechanism produces a much richer variety of topological objects, such as merons (half skyrmions) and bimerons, which, unlike flat vortices, carry a true topological charge. The appearance/disappearance of these structures on warming/cooling is clearly illustrated in the X-PEEM images, providing a visually compelling 'movie' of a magnetic topological phase transition in action. Driven by current-based spin torques from the Pt over-layer, some of these AFM textures could emerge as prime candidates for low-energy antiferromagnetic spintronics at room temperature

[1] Kibble, T. W. B. "Topology of cosmic domains and strings." J. Phys. A: Math. Gen. 9, 1387–1398 (1976); Zurek, W. H. Cosmological experiments in superfluid helium? Nature 317, 505–508 (1985).
[2] Chmiel, F. P. et al. "Observation of magnetic vortex pairs at room temperature in a planar α- Fe2O3/Co heterostructure." Nature Materials 17, 581–585 (2018).
[3] Jani H. et al., "Half-skyrmions and Bimerons in an antiferromagnetic insulator at room temperature", arXiv:2006.12699 [cond-mat.mtrl-sci]

Title: Fermi arc transport and quantum Hall effect in topological Semimetals
Author: Faxian Xiu
Address: Fudan University, Jiangwan Campus, 2205 Song Hu Road, Shanghai, 200433, China

Abstract:

Dirac semimetal is a new type of topological quantum material, which is protected by lattice symmetry. Its energy band has a degenerate Dirac cone structure, which is called "three-dimensional graphene". Dirac Semimetals can be used as the parent materials of a series of novel quantum states. When the symmetry is broken, the system can evolve into a topological insulator, Weyl semimetal, and topological superconductor, etc. Further study of these symmetry-breaking-induced phase transitions can enable a deeper understanding of topological quantum materials. Due to the prospects of three-dimensional Dirac semimetals in the fields of high-dimensional topological materials and topological phase transitions, as well as the potential application in quantum computing, high-mobility conductive materials, magnetic sensors and so on, a research upsurge of Dirac semimetals has emerged worldwide. Our previous study suggests that the topological Dirac/Weyl semimetals have exotic chiral charge pumping [1] and ultrahigh conductivity properties [2]. This report will focus on another important characteristic of topological semimetals - Fermi arc surface states and Weyl orbits formed by the coupling of upper and lower Fermi arcs [3, 4]. In our experiment, the wedge-shaped sample is used to achieve controllable thickness change so that the time required for the electrons to tunnel in different thickness regions is different, which leads to the change of the corresponding orbit states. It is found that different from the conventional quantum Hall effect based on two-dimensional surface states, the energy of cyclotron orbit is affected by the sample thickness. At the same time, by changing the direction of magnetic fields, it is found that the orbital energy is also affected by the relative position of the magnetic field and crystal orientation. Based on these two important pieces of evidence, we have successfully proved that the quantum Hall effect in cadmium arsenide nanostructures originates from the three-dimensional Weyl orbit [3, 4]. The realization of the three-dimensional quantum Hall effect overcomes the dimensional limit, which provides a new idea and experimental basis for the quantum transmission of electrons in three-dimensional space in the future.

[1] C. Zhang et al, Room-temperature chiral charge pumping in Dirac semimetal, Nature Communications 8, 13741 (2017).
[2] C. Zhang et al, Ultrahigh conductivity in Weyl semimetal NbAs nanobelts, Nature Materials 18, 482–488 (2019).
[3] C. Zhang et al, Evolution of Weyl-orbit and quantum Hall effect in Dirac semimetal Cd3As2, Nature Communications 8, 1272 (2017).
[4] C. Zhang et al, Quantum Hall effect based on Weyl orbits in Cd3As2, Nature 565, 331 (2019).

Title: From chemical bonds to topology
Author: Leslie M Schoop
Address: Department of Chemistry, Princeton University, Princeton, NJ, 08540, USA

Abstract:

In the discipline of chemistry, it is common to have guidelines and heuristics that help to predict how chemical reactions will proceed. We are interested to expand these heuristics to understand if we can predict topological materials. In this talk, I will show how delocalized chemical bonds in certain structural networks allow us to define chemical descriptors that predict band inversions. Using these descriptors, we found a layered, antiferromagnetic van der Waals material with very high mobility. These properties have previously not coexisted in a material that can be mechanically exfoliated. We further implemented our heuristics to discover novel complex topological phases, including magnetic ones, and phases that are in competition with complex structural distortions.

If time allows, I will also briefly discuss the concept of chemical exfoliation. With this method, we can exfoliate materials for which the scotch tape method fails. I will show how we were able to synthesize a new chromium chalcogenide this way, which might be a new 2D magnetic material.

Title: Switchable spin states in topological insulators

Author: Alessandra Lanzara

Address: UC Berkeley, USA

Abstract:

The realization of materials with topological order provides new mechanism for the development of novel electronic and optical devices enabling spin and quantum transport phenomena, utilizing the robust and spin polarized currents that are present in these materials. However, the utility of these systems for device and quantum computing applications, relies in the ability to control and manipulate such currents, as well as in the ability to generate long lived carriers able to travel to a reasonable distance in order to perform logic operations. In this talk I will present a full characterization of spin texture in topological insulator. I will discuss how topologically protected spin-locked surface states emerge through a topological phase transition and how spin currents can be optically controlled. We reveal the emergence of symmetry protected spin polarized surface currents and show that they can be easily realized and tuned in both magnitude and duration, while also giving rise to the appearance of a microsecond metastable state. We discuss how, this method of controlling spin and spacing of quantum well states at ultrafast timescales, provides a direct means to producing novel light-modulated spin-and charge based devices.

Title: Topological Photonic Crystals and their Applications in Nanophotonics

Author: Jian-Wen Dong

Address: School of Physics & State Key Laboratory of Optoelectronic Materials and Technologies, Sun Yat-sen University, Guangzhou 510275, China

Abstract:

Photonic crystals (PCs) are one of the important systems to realize light field manipulations in nanophotonics. For example, photonic waveguides are achieved in the W1-type PCs, unidirectional and robust transport of edge states are achieved by the boundary and corner decoration of PCs. However, the design process is complicated because there are many degrees of freedom to be determined. Recently, by employing topology into PCs, we can easily achieve the unidirectional and robust transport of edge states which are predicted by the simple topological invariant [1]. In this talk, we show our demonstrations of topological PCs and their applications in nanophotonics. We experimentally realized the spin-Hall topological PCs in a uniaxial metacrystal waveguide and the valley-Hall topological PCs in the silicon-on-insulator platform [2, 3]. Based on the valley-polarized edge states, we demonstrated some photonic phenomena such as robust waveguides, photonic routing, layer-dependent light transport, and wavelength-division multiplexing light transport. In addition, based on the high-order topological PCs, we also achieved the photonic cavity [4]. The research about topological PCs not only enriches the understanding of light flow control, but also propose a new designing scheme of novel applications in nanophotonics.

[1] T. Ozawa, H. M. Price, A. Amo, N. Goldman, M. Hafezi, L. Lu, M. C. Rechtsman, D. Schuster, J. Simon, O. Zilberberg, and I. Carusotto, "Topological photonics," Reviews of Modern Physics 91, 015006 (2019).
[2] W.-J. Chen, S.-J. Jiang, X.-D. Chen, B. Zhu, L. Zhou, J.-W. Dong, and C. T. Chan, "Experimental realization of photonic topological insulator in a uniaxial metacrystal waveguide," Nature communications 5, 5782 (2014).
[3] X.-T. He, E.-T. Liang, J.-J. Yuan, H.-Y. Qiu, X.-D. Chen, F.-L. Zhao, and J.-W. Dong, "A silicon-on-insulator slab for topological valley transport," Nature communications 10, 872 (2019).
[4] X.-D. Chen, W.-M. Deng, F.-L. Shi, F.-L. Zhao, M. Chen, and J.-W. Dong, "Direct Observation of Corner States in Second-Order Topological Photonic Crystal Slabs," Physical Review Letters 122, 233902 (2019).

Title: Topological states in sonic crystals
Author: Chunyin Qiu
Address: Department of Physics, Wuhan University, China

Abstract:

Since the discovery of topological insulators, topological phases of quantum matter have been one of the most active topics in multidiscipline fields of physics, ranging from condensed matter physics to photonics and acoustics, and so on. Interestingly, the artificial crystals for classical waves have been demonstrated to be exceptional platforms for exploring the highly elusive topological physics, benefited from the well-controlled structure design and the less demanding signal detection. In this talk, I will introduce our recent progress on topological sonic crystals, including valley-projected edge transport [1], Weyl and Dirac sonic crystals [2-4], and pseudo-magnetic field in acoustics [5].

[1] J. Lu et al., Observation of topological valley transport of sound in sonic crystals, Nat. Phys., 13, 369-374 (2017).
[2] H. He et al., Topological negative refraction of surface acoustic waves in a Weyl phononic crystal, Nature 560, 61-64 (2018).
[3] H. He et al., Observation of quadratic double Weyl points and associated double-helicoid topological surface states, Nature Communications, 11:1820 (2020).
[4] X. Cai et al., Symmetry-enforced three-dimensional Dirac phononic crystals, Light: Science & Applications 9:38 (2020).
[5] X. Wen et al., Acoustic Landau quantization and quantum Hall-like edge states, Nat. Phys. 15, 352–356 (2019).

Title: Acoustic analogues of topological insulators
Author: Cheng He, Ming-Hui Lu and Yan-Feng Chen
Address: Nanjing University, Nanjing 210093, China

Abstract:

The discovery of topological phases in condensed matter physics over the past decades has inspired the studies in classical wave systems such as acoustics. The fascinating topological design of artificial acoustic crystals enables unique backscattering-immune sound transport. Here, I will talk about our recent progress in acoustic topological insulators. 1. By manipulating the band inversion in a graphene-like acoustic crystal, we successfully realized the first 2D acoustic topological insulator for airborne sound [1]. 2. We analyzed the key factor to realize bosonic topological insulators, i.e., utilizing artificial symmetries to construct pseudospin-1/2 and fermionic-like pseudo-time-reversal-symmetry. Our experiment on elastic wave topological insulator demonstrates such pseudospin transport [2,3]. 3. we explored various types of 3D acoustic topological materials, including pseudospin-valley coupled saddle surface states, semi-Dirac surface states, and acoustic analogues of multi-order 3D topological insulators [4-6]. Our results about topological engineering of sound transport may promise high efficiency and unique function for the next generation of acoustic devices.

/1] C. He, X. Ni et al., Nat. Phys. 12, 1124 (2016).
[2] C. He, X.-C. Sun et al., PNAS 113, 4924 (2016)
[3] S.-Y. Yu, C. He et al., Nat. Commun. 9, 3072 (2018).
[4] C. He, S.-Y. Yu et al., Nat. Commun. 9, 4555 (2018).
[5] C. He, S.-Y. Yu et al., Phys. Rev. Lett. 123, 195503 (2019).
[6] C. He, H.-S. Lai et al., Nat. Commun. 11, 2318 (2020).

Title: Topology in Magnetic Materials and Engineered Devices

Author: Bogdan A. Bernevig
Address: Princeton University, USA

Abstract:

Title: Topological magneto-optical effect and its quantization in noncoplanar antiferromagnets

Author: Yugui Yao
Address: Key Lab of Advanced Optoelectronic Quantum Architecture and Measurement (MOE), & School of Physics, Beijing Institute of Technology, Beijing 100081, China

Abstract:

Magneto-optical (MO) effects, referring to changes in the polarization state of light upon interacting with magnetic matter, are one of the most basic phenomena in solid-state physics. MO effects have been known for more than a century, whose origin is usually ascribed to the simultaneous presence of band exchange splitting and spin-orbit coupling. However, using a tight-binding model and first-principles calculations, we show that topological MO effects, in analogy to the topological Hall effect, can arise in noncoplanar antiferromagnets entirely due to the scalar spin chirality instead of spin-orbit coupling. Here, the band exchange splitting and spin-orbit coupling are not required for topological MO effects. Moreover, we discover that the Kerr and Faraday rotation angles in two-dimensional insulating noncoplanar antiferromagnets can be quantized in the low-frequency limit, implying the appearance of quantum topological MO effects, accessible by time-domain THz spectroscopy.

[1] Wanxiang Feng, Xiaodong Zhou, Jan-Philipp Hanke, Guang-Yu Guo, Stefan Blugel, Yuriy Mokrousov, and Yugui Yao*, “Topological Magneto-Optical Effect and Its Quantization in Noncoplanar Antiferromagnets”, Nat. Comm. 11,118 (2020).

Title: Bulk and Surface Dirac and Weyl States in Transition-Metal Dichalcogenides and NbGeSb

Author: P.D.C. King
Address: School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Abstract:

In this talk, I will look at the interplay between crystalline symmetry and spin-orbit coupling in stabilising bulk and surface Dirac/Weyl states in solids. First, I will consider the broad family of the transition-metal dichalcogenides. Using a combination of spin- and angle-resolved photoemission experiments together with first-principles calculations, I will show that both the common 1T and 2H structural polymorphs are natural hosts of ladders of type-I and type-II bulk Dirac cones and topological surface states and resonances [1-3]. I will demonstrate how these arise from the chalcogen p-orbital manifold as a very general consequence of their trigonal crystal field and rotational symmetry, and as such can be expected across a large number of compounds, opening routes to tune and ultimately exploit the topological physics of TMDs. Secondly, I will consider the surface electronic structure of NbGeSb, an isostructural analogue of the bulk Dirac nodal line system ZrSiS. We find how two-dimensional Weyl-like states are created from band inversions between manifolds of spin-orbit coupled surface states, protected by a mirror symmetry of the crystal surface [4]. This suggests new potential to create topologically- and symmetry-protected states via band inversions of surface states.

This work was performed in close collaboration with O.J. Clark and I. Marković (U. St Andrews), M.S. Bahramy (U. Tokyo), J. Alaria (Liverpool), and colleagues from St Andrews, Liverpool, Tokyo, Diamond, SOLEIL, Elettra, HiSOR, Max-IV, Trondheim, Suranaree, and SNU.

[1] Bahramy et al. Nature Materials 17 (2018) 21
[2] Clark et al. Phys. Rev. Lett. 120 (2018) 156401
[3] Clark et al., Electronic Structure 1 (2019) 014002
[4] Marković et al., Nature Communications 10 (2019) 5485

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes

Notes