Realization of Practical Eightfold Fermions and Fourfold van Hove Singularity in $TaCo_2Te_2$

Hongtao Rong[1*], Zhenqiao Huang[1,7*], Xin Zhang[2,8*], Shiv Kumar[3*], Fayuang Zhang[1], Chengcheng Zhang[1], Yuan Wang[1], Zhanyang Hao[1], Yongqing Cai[1], Le Wang[1], Cai Liu[1], Xiao-Ming Ma[1], Shu Guo[1], Bing Shen[4], Yi Liu[5], Shengtao Cui[5], Kenya Shimada[3], Quansheng Wu[6,10], Junhao Lin[1], Yugui Yao[2,8], Zhiwei Wang[2,8,9#], Hu Xu[1#], and Chaoyu Chen[1#]

[1] *Shenzhen Institute for Quantum Science and Engineering (SIQSE) and Department of Physics, Southern University of Science and Technology (SUSTech), Shenzhen 518055, China.*

[2] *Centre for Quantum Physics, Key Laboratory of Advanced Optoelectronic Quantum Architecture and Measurement, School of Physics, Beijing Institute of Technology, Beijing 100081, China.*

[3] *Hiroshima Synchrotron Radiation Centre, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-0046, Japan.*

[4] *School of Physics, Sun Yat-Sen University, Guangzhou 510275, China.*

[5] *National Synchrotron Radiation Laboratory, University of Science and Technology of China, Hefei, Anhui 230029, China.*

[6] *Beijing National Laboratory for Condensed Matter Physics, and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China.*

[7] *Department of Physics, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China.*

[8] *Beijing Key Lab of Nanophotonics and Ultrafifine Optoelectronic Systems, Beijing Institute of Technology, Beijing 100081, China.*

[9] *Material Science Center, Yangtze Delta Region Academy of Beijing Institute of Technology, Jiaxing 314011, China.*

[10] *University of Chinese Academy of Sciences, Beijing 100049, China.*

Keywords: Topological states, eightfold fermions, fourfold van Hove singularity, hourglass fermion

Searching for new elementary excitation/quasiparticles is a key pursuit of condensed matter physics. In the past decades, Weyl and Dirac type low-energy quasiparticles, in analog to relativistic massless Weyl and Dirac fermions in high-energy physics, have been realized based on materials such as graphene, topological insulator, and Weyl/Dirac semimetal. Moreover, the 230 space groups in condensed matter physics impose fewer constraints on the allowed types of fermions. New fermionic quasiparticles beyond high-energy physics, including threefold, sixfold, and eightfold fermions, can emerge. So far, while Weyl (twofold), threefold, Dirac (fourfold), and sixfold quasiparticles have been observed in quantum materials[1-12], eightfold fermions remain to be realized. Based on a nonsymmorphic crystal $TaCo_2Te_2$, we provide a clear spectroscopic signature of eightfold degenerate fermions protected by the combination of crystalline and time-reversal symmetry.

We establish $TaCo_2Te_2$ as a conjoint topological and quantum critical platform with handful stimuli available to tune its physical properties. Chemical substitution or applying strain may introduce long range magnetic order and magnetic quantum critical point is expected. The negligible SOC leads to the practical realization of eightfold fermions, which, according to theoretical analysis, serves as a topological quantum critical point. Symmetry breaking via magnetic field or uniaxial strain may lead to various topologically trivial or nontrivial phases such as Dirac point, Weyl point or nodal lines. Consequently, our findings will stimulate broad research interest from subfields of condensed matter physics such as quantum transport, strong correlation, material synthesis and topological states of matter.

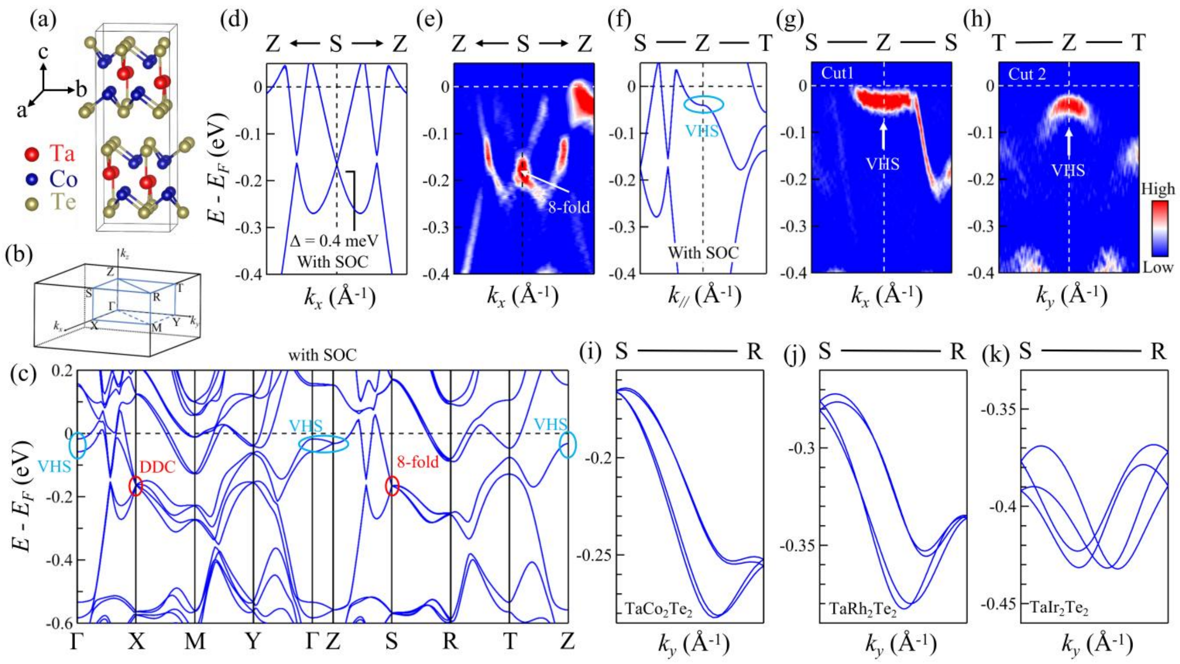

FIGURE 1. Crystal structure, eightfold fermion, fourfold van Hove singularity and hourglass in $TaCo_2Te_2$. (a) Crystal structure. (b) 3D bulk BZ. (c) DFT calculated dispersions along the high-symmetry path with considering SOC. (d, e) DFT calculated dispersions and ARPES dispersion around eightfold fermion. (f-h) DFT calculated dispersions and ARPES dispersion around van Hove singularity. (i-k) DFT predicted hourglass fermions in TaT_2Te_2 (T= Co, Rh and Ir).

REFERENCES

1. A. Alexandradinata, Zhijun Wang & B. Andrei Bernevig. *Physical Review X* **6**, 021008 (2016)
2. B. Bradlyn, J. Cano, Z. Wang, M. G. Vergniory, C. Felser, R. J. Cava & B. A. Bernevig. *Science* **353**, 5037 (2016)
3. S. M. Huang, S. Y. Xu, I. Belopolski, C. C. Lee, G. Chang, T. R. Chang, B. Wang, N. Alidoust, G. Bian, M. Neupane, D. Sanchez, H. Zheng, H. T. Jeng, A. Bansil, T. Neupert, H. Lin & M. Z. Hasan. *Proc Natl Acad Sci USA* **113**, 1180-1185 (2016)
4. Z. Wang, A. Alexandradinata, R. J. Cava & B. A. Bernevig. *Nature* **532**, 189-194 (2016)
5. Hongming Weng, Chen Fang, Zhong Fang & Xi Dai. *Physical Review B* **93**, 241202 (2016)
6. B. J. Wieder, Y. Kim, A. M. Rappe & C. L. Kane. *Phys Rev Lett* **116**, 186402 (2016)
7. Ziming Zhu, Georg W. Winkler, QuanSheng Wu, Ju Li & Alexey A. Soluyanov. *Physical Review X* **6**, 031003 (2016)
8. Qihang Liu & Alex Zunger. *Physical Review X* **7**, 021019 (2017)
9. Benjamin J. Wieder, Barry Bradlyn, Zhijun Wang, Jennifer Cano, Youngkuk Kim, Hyeong-Seok D. Kim, Andrew M. Rappe, C. L. Kane & B. Andrei Bernevig. *Science* **361**, 246-251 (2018)
10. Weikang Wu, Zhi-Ming Yu, Xiaoting Zhou, Y. X. Zhao & Shengyuan A. Yang. *Physical Review B* **101**, 205134 (2020)
11. P. J. Guo, Y. W. Wei, K. Liu, Z. X. Liu & Z. Y. Lu. *Phys Rev Lett* **127**, 176401 (2021)
12. Jennifer Cano, Barry Bradlyn & M. G. Vergniory. *APL Materials* **7**, 101125 (2019)