Magnetic Weyl semimetal finally confirmed

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Recently, a couple of *Science* papers [1,2] have reported the existence of Fermi arcs on the surface of a ferromagnetic compound, namely $\text{Co}_3\text{Sn}_2\text{S}_2$, which was first proposed to be a magnetic Weyl semimetal (WSM) according to the giant anomalous Hall effect [3,4]. The new evidence is in agreement with this proposal, suggesting that the magnetic WSM has been found after a nearly eight year research [5,6]. This finding, along with the discovery of nonmagnetic WSMs of TaAs family in 2015 [7,8], has completed the WSM classification. In comparison with the nonmagnetic WSM, magnetic WSM has a long-range magnetic order coupled with Weyl nodes. Furthermore, it offers more ways to control and explore the properties of WSMs.

WSM is a special metal and its Fermi surface comprises band crossing points only, which are known as Weyl nodes, because the low-energy excitation of electrons around each node has been described by the Weyl equation, as proposed by Hermann Weyl in 1929. This equation predicts a new fermion, namely Weyl fermion, which is massless and has definite chirality. Although Weyl fermions have not been discovered in any high-energy physics experiment, their quasiparticles emerge in WSMs and exhibit themselves in some unique ways, which is not possible for real Weyl fermions. For example, when Weyl nodes are projected onto the surfaces of WSMs, Fermi arcs connecting the projections of

opposite chiral nodes are observed, as shown in Figure 1. The number of connections to each projection depends on the topological charge of the projected Weyl nodes, whereas patterns of Fermi arcs depend on the details of the terminating surface, including the symmetries retained, atomic structure, possible dangling bonds, and its chemical modification. Nevertheless, Fermi arcs possess some topological invariant properties, such as their existence, start and end points, spin texture [9], and continuity of the two partner arcs on the top and bottom surfaces tunneling through the bulk Weyl nodes [10]. These invariances originate from the nontrivial band topology of Weyl nodes in bulk and are used as fingerprints of the existence of Weyl nodes.

Direct observations of Fermi arcs, Weyl nodes, and their relation are necessary to confirm the existence of WSM state. The first successful story is on TaAs family compounds [8]. The nonmagnetic feature makes the spin-resolved and/or angle-resolved photoemission spectroscopy (ARPES) highly effective in identifying these, especially when measurements are accurately simulated by first-principle calculations. However, ARPES possesses some limitation when applied to magnetic materials because the complex magnetic domains in sample blur the signals and external magnetic field for alignment is prohibited. Liu et al. [1] have attempted to overcome these limitations in ferromagnetic $\text{Co}_3\text{Sn}_2\text{S}_2$. They have unambiguously observed Fermi arcs and related bulk Weyl nodes. $\text{Co}_3\text{Sn}_2\text{S}_2$ has a planar Kagome lattice of Co

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Figure 1 (Color online) Weyl cones in WSM and Fermi arcs connecting their projections onto the top and bottom surfaces.

ions, leading to quite larger hysteresis loop in magnetization than HgCr_2Se_4 [6], which is crucial for successful ARPES measurements. Surface-sensitive techniques, such as scanned tunneling microscopy (STM), are another way to study Fermi arcs. Morali et al. [2] have identified that the Fermi arcs of $\text{Co}_3\text{Sn}_2\text{S}_2$ have surface termination dependence, as analyzed by the quasi-particle interference pattern in STM. Therefore, these two spectroscopy measurements have supplied the most comprehensive evidence on the magnetic WSM state in $\text{Co}_3\text{Sn}_2\text{S}_2$.

The pursuit of both nonmagnetic and magnetic WSMs has succeeded considerably. This has stimulated extensive theoretical and experimental efforts to explore intriguing physical properties and effects associated with Weyl nodes, including anomalous Hall effect, anomalous Nernst effect, chiral anomaly effect, zero sound [11], nonlinear optical effect [12], three-dimensional quantum Hall effect [13], unique charge and spin current [14], and catalysis [15]. High pressure [16,17] and other ways to introduce coupling with magnetism, superconductivity, ferroelectricity, phonon, photon, and magnon will bring us more phenomena in WSMs.

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