QUANTUM MATERIALS

Topology and correlations on the kagome lattice

Both a Dirac band and a flat band — signatures of topology and correlation — are found in a prototypical antiferromagnetic kagome lattice compound FeSn.

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In the late 1980s it was realized, building on earlier work[1], that the antiferromagnetic kagome lattice may be the most frustrated two-dimensional (2D) magnetic system that one can construct. In fact, it was thought that it may never order at any temperature, and it was later realized[2] that this is not just a disordered paramagnet, but a new state called a spin liquid[3]. For a long time, it was this potential for hosting a quantum spin liquid that drove interest in the kagome lattice. However, more recently[4–6] it was noted that the kagome lattice may be a host to both topologically protected bands as well as non-dispersing or flat bands. Now, writing in *Nature Materials*, Mingu Kang and colleagues[7] observed both Dirac bands and flat bands in a three-dimensional (3D) antiferromagnetic kagome lattice FeSn.

Structurally, FeSn contains two alternating layers labelled K and S, as shown in Fig. 1a. The K layer consists of a kagome net of Fe atoms (Fig. 1b) that alternates with the Sn-containing S layer (Fig. 1c) vertically along the *c* axis. As such, the neighbouring kagome layers maintain a large separation (as there is only one K layer in the unit cell), making FeSn close to a 2D kagome lattice, despite its 3D crystal structure. Such a layered structure also allowed Kang and colleagues to exfoliate FeSn so as to expose the S and K layers individually and study their contributions to the electronic structure by means of a surface-sensitive probe — angle-resolved photoemission spectroscopy (ARPES). Additionally, the collinear antiferromagnetic stacking of the ferromagnetic kagome Fe planes made the interpretation of the measurement much more straightforward than in some other similar Fe–Sn compounds that have complicated magnetic spirals.

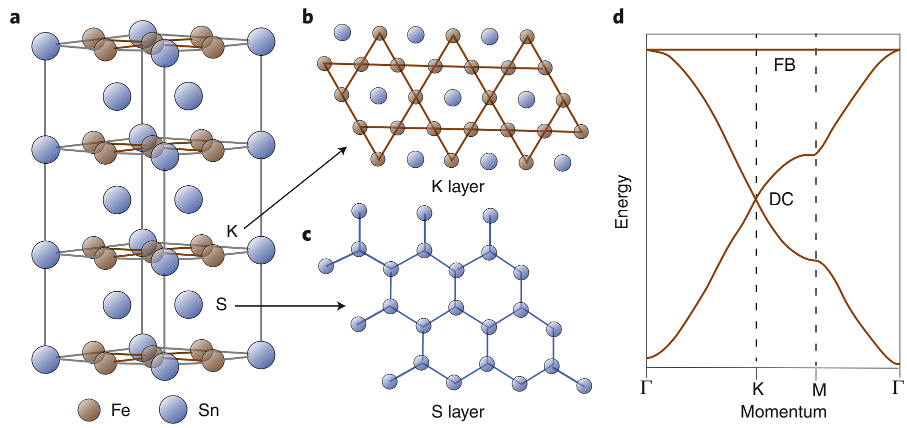

Fig. 1 | Crystal and electronic structure of a kagome lattice. a, Structure of FeSn. **b**, Kagome lattice formed by Fe atoms. **c**, Layer of Sn atoms. **d**, Schematic of electronic structure as may be measured using angle-resolved photoemission (ARPES). FB, flat band; DC, Dirac cone.

The Fermi surface mapped out by the ARPES experiment on the kagome termination (K layer) showed a circular electron pocket at the corner of the hexagonal Brillouin zone (K point). Such a Fermi surface is ascribed to the Dirac bands predicted by tight-binding calculations for the kagome lattice (that the authors confirmed by full ab initio calculations). Indeed, the energy–momentum dispersion measured across the K point showed the crossing of linearly dispersive bands slightly (0.43 eV) below the Fermi level, forming a Dirac cone (DC1) and establishing the Dirac fermiology of the kagome-derived bands. A similar experiment carried out on the Sn termination (S layer) showed two electron pockets at the K point — a circular pocket arising from the DC1, and a triangular pocket arising from a new Dirac cone DC2 with crossing at about 0.31 eV below the Fermi level. The inequivalence of the electronic spectra from the two terminations allowed the team to establish the bulk and surface origin of DC1 and DC2, respectively. Additionally, the observation that neither of the Dirac cones has shown any appreciable dispersion in the third direction (perpendicular to the planes) revealed the 2D nature of both of the Dirac cones.

Kang and colleagues also utilized magneto-quantum oscillation phenomena to access different properties of the Fermi surface. This is a bulk probe and measures the areas of extremal Fermi surface cross-sections, perpendicular to the external magnetic field. Three such measured cross-sections were insensitive to the magnetic field direction, typical for a quasi-isotropic closed 3D Fermi surface pocket, while at least one cross-section showed an angular dependence characteristic of 2D bands. A more detailed analysis allowed the researchers to relate this cross-section to DC1, whereas no cross-section corresponding to DC2 was found in this bulk probe, further confirming the bulk and surface nature of DC1 and DC2, respectively.

Arguably the most surprising finding was the observation, by ARPES, of an extremely flat band about 0.23 eV below the Fermi level. Indeed, first of all, in real life (and in ab initio calculations) this band is liable to acquire dispersion, typically of the order of at least several tenths of an electronvolt. Second, as shown schematically in Fig. 1d, the 'classical' kagome flat band is situated well above the Dirac points. Indeed, the ab initio calculation reported by Kang et al. fully agree with this reasoning. Their calculations do not show any flat or low-dispersion feature below the Fermi level. So, as tempting as it is to identify the observed flat band with the famous flat band in the single-orbital nearest-neighbour kagome model, it is probably not the case. The nature of this band, showing zero dispersion within the experimental resolution, therefore remains a mystery.

Dirac bands, in different context, have been observed in numerous 2D and 3D materials. To some extent, this is thanks to the fact that they enjoy considerable topological protection. A topological flat band is another entity with promising prospects for the realization of the fractional quantum Hall effect[8–11]. However, coexisting Dirac and flat bands in magnetic materials — as identified by Kang and colleagues — are much more rare, and in many ways more interesting. Flat bands, at least the flat bands of the type known in kagome Hamiltonians (Fig. 1d), are parametric, rather than topological, and therefore difficult to observe. In this regard, Kang and colleagues' work provides new prospects for the field of correlated topological materials. ❐

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Published online: 27 January 2020
https://doi.org/10.1038/s41563-019-0589-8

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