Semi-Dirac Fermions in a Topological Metal

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Topological semimetals with massless Dirac and Weyl fermions represent the forefront of quantum materials research. In two dimensions (2D), a peculiar class of fermions that are massless in one direction and massive in the perpendicular direction was predicted 16 years ago. These highly exotic quasiparticles—the semi-Dirac fermions—ignited intense theoretical and experimental interest but remain undetected.

Using the magneto-infrared spectroscopy facilities (SCM3) at the MagLab, we identified the smoking-gun signature of semi-Dirac fermions in an unexpected system: a three-dimensional (3D) topological semimetal known as ZrSiS (Fig. 1a). The Fermi surface of ZrSiS (Fig. 1b) consists of coexisting electron (blue) and hole (red) pockets, originating from the underlying Dirac nodal-lines. Under strong in-plane magnetic fields (green arrow), the electrons are quantized in the 2D planes perpendicular to the field, which host the semi-Dirac fermions at the nodal-line crossing-points (Fig. 1c). Above a critical field of around B = 8T, we observed Landau level transitions following a unique $B^{2/3}$ power-law behavior (Fig. 1d), distinct from conventional massive fermions and massless Dirac fermions. Remarkably, this $B^{2/3}$ power-law of the Landau levels is precisely the signature of semi-Dirac fermion in the original predictions.

ZrSiS also exhibits strong electron mass enhancement in high fields and low temperatures, which is attributed to electronic correlations. The observed 2D semi-Dirac fermions in ZrSiS offers a unique platform to study novel 2D quasiparticles and their interaction effects in natural bulk 3D crystals.

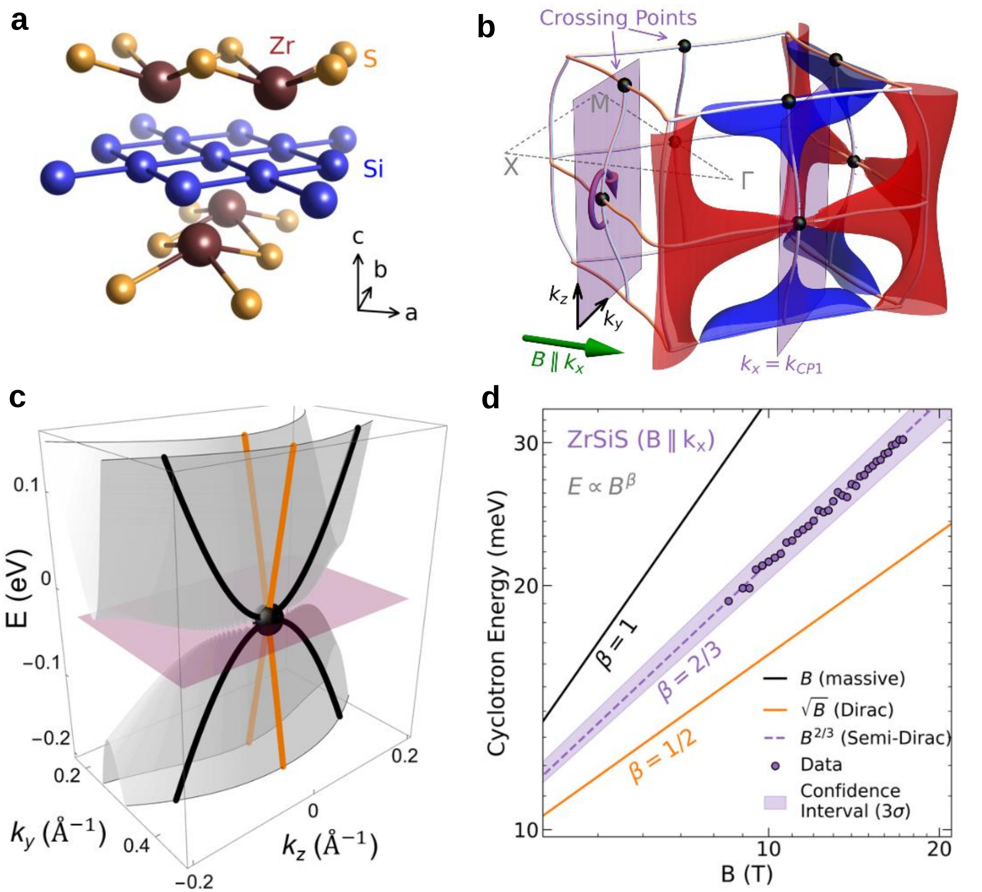

Figure. 1: ***a)*** *Lattice structure of ZrSiS.* ***b)*** *Calculated Fermi surface and nodal-line structure of ZrSiS. Black spheres indicate the crossing points (CPs) of multiple nodal lines. The circular purple arrow illustrates the cyclotron motion around one of the CPs for magnetic field (green arrow) applied along k_x (a axis of the crystal)* ***c)*** *Calculated band structure of ZrSiS near the semi-Dirac point (black sphere).* ***d)*** *Comparison of the power-law behavior for the cyclotron energy versus magnetic field in various fermions in a log-log plot.*

Facilities and instrumentation used: DC Field Facility: SCM3 (17 T) and SCM2 (18T).

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