

## Unconventional Fermi surface in an insulating state

B. S. Tan<sup>1</sup>, Y.-T. Hsu<sup>1</sup>, B. Zeng<sup>2</sup>, M. Ciomaga Hatean<sup>3</sup>, N. Harrison<sup>2</sup>, Z. Zhu<sup>2</sup>, M. Hartstein<sup>1</sup>, M. Kiourlappou<sup>1</sup>, A. Srivastava<sup>1</sup>, M. D. Johannes<sup>4</sup>, T. P. Murphy<sup>2</sup>, J.-H. Park<sup>2</sup>, L. Balicas<sup>2</sup>, G. G. Lonzarich<sup>1</sup>, G. Balakrishnan<sup>3</sup>, Suchitra E. Sebastian<sup>1</sup>



1. University of Cambridge; 2. National High Magnetic Field Laboratory; 3. University of Warwick; 4. Naval Research Laboratory Funding Grants: G.S. Boebinger (NSF DMR-1157490); S. E. Sebastian (ERC Grant Agreement 337425); L. Balicas (DOE-BES DE-SC0002613); G.Balakrishnan (EPSRC EP/L014963/1); N.Harrison (DOE-BES "Science of 100 Tesla"; G. G. Lonzarich (EPSRC EP/K012894/1).

Samarium hexaboride, SmB<sub>6</sub>, is a Kondo insulator at low temperatures due to an energy gap formed by collective hybridization between d- and f-electrons. Magnetic field measurements reveal a surprising finding of quantum oscillations arising from the insulating bulk of  $SmB_{6}$  (Fig. A).

Electrical transport measurements find a strong insulating character of SmB<sub>6</sub>, with a thousand-fold increase in resistance exhibited when the sample is cooled below 10K. However, using torgue magnetometry in the 45 T hybrid magnet, guantum oscillations in the magnetization are clearly revealed, the angular dependence of which reveals a Fermi surface that corresponds to a large three-dimensional section occupying half the Brillouin zone (Fig. C).

Strikingly, at dilution refrigerator temperatures, the quantum oscillation amplitude measured as a function of temperature in SmB<sub>e</sub> deviates strongly from the well known Lifshitz-Kosevich form that is characteristic of fermionic quasiparticles in interacting metals (Fig. B).

The unconventional character of the SmB<sub>6</sub> ground state is therefore revealed by simultaneous electrically insulating behavior and quantum oscillations in the magnetisation, the temperature dependence of which deviates from the characteristic Lifshitz-Kosevich form universally observed in interacting metals.

Facilities: 45 T hybrid & 35 T resistive magnets at DC field facility.



SmB<sub>6</sub> in which a substantial shift is made to the Fermi energy.

Citation: Unconventional Fermi surface in an insulating state, B. S. Tan, Y.-T. Hsu, B. Zeng, M. Ciomaga Hatean, N. Harrison, Z. Zhu, M. Hartstein, M. Kiourlappou, A. Srivastava, M. D. Johannes, T. P. Murphy, J.-H. Park, L. Balicas, G. G. Lonzarich, G. Balakrishnan, S. E. Sebastian, Science 349 (2015) 287-290.