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Collective coherence above T_c in kagome metals?

Many-body interference in kagome crystals
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Recommended with a Commentary by Jörg Schmalian, Karlsruhe Institute of Technology

The kagome metals AV_3Sb_5 (A = K, Rb, Cs) form a class of layered compounds where itinerant electrons occupy a geometrically frustrated lattice hosting Dirac crossings and Van Hove singularities near the Fermi level [1]. These ingredients give rise to several correlated phenomena, including charge-density-wave (CDW) order at $T_{\mathrm{CDW}} \approx 94$ K and superconductivity at $T_c \approx 2.5$ K. Among them, CsV_3Sb_5 has received particular attention due to an additional crossover near $T' \approx 30$ K, where various probes detect anomalies in transport, thermoelectric, and magnetic responses. The microscopic nature of this state remains debated, with translation and time-reversal symmetry-breaking loop currents a prominent scenario.

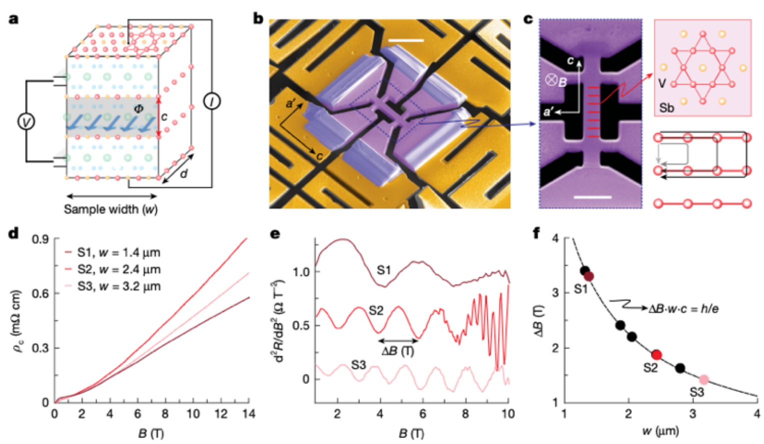

Figure 1: Figure from C. Guo et al. with **(a)** a sketch of the geometry for out-of-plane transport, **(b)** SEM image of the microstructure, **(c)** a close-up of the device, **(d)** the magnetoresistance for different sample widths w, **(e)** it's second derivative, and **(f)** the dependence of the oscillation period of different samples in comparison with Eq. (1).

The paper by Guo *et al.* reports evidence that the state below T' supports long-range electronic coherence in the normal state, i.e. for $T_c < T < T'$. Using micro-structured pillars of CsV_3Sb_5 oriented along the *c*-axis, the authors measured interlayer magneto-transport under in-plane magnetic fields. The magnetoresistance displays field-periodic oscillations with period ΔB satisfying

$$\Delta\mathrm{B}\ \mathrm{A} = \mathrm{h}/\mathrm{e}, \qquad (1)$$

where the area that encompasses the flux is fully consistent with $A = w\,c$. Here, w is the pillar width and c the interlayer spacing (see Fig. 1). This scaling is consistent with the oscillations arising from an h/e flux periodicity corresponding to one flux quantum between adjacent kagome planes. The effect persists up to $T' \approx 30$ K and disappears rapidly when the field is tilted a few degrees out of plane, significantly constraining the allowed flux geometry of the effect.

These findings suggest a comparison with the metallic delafossite $PdCoO_2$, a material known to lie deep in the ballistic transport regime with exceptionally long elastic mean-free paths and exhibiting qualitatively similar h/e-period oscillations that are attributed to ballistic single-particle transport [2]. However, there are key differences: $PdCoO_2$ is characterized not only by its extraordinarily long elastic mean-free path, but also by remarkably weak inelastic dephasing, owing to strong phonon-drag effects at low temperatures [3], which help preserve coherent single-particle propagation. Moreover, the rapid suppression of oscillations in CsV_3Sb_5 upon even a slight tilt of the magnetic field out of the plane appears difficult to reconcile with the single-particle mechanism invoked for $PdCoO_2$.

In contrast to robust single-particle transport in $PdCoO_2$, several additional observations support a distinct origin of the field oscillations in CsV_3Sb_5: The amplitude and periodicity of the oscillations scale only with device geometry and the elementary flux quantum and, hence, are independent of details of the Fermi surface. Rotating the magnetic field within the kagome plane leads to discrete frequency switching which is tied to the sample's shape. Again, this is rather different from the smooth angular evolution characteristic of single-particle interference. It thus appears that the oscillations arise from an interference of a collective many-body state extending across the sample width and between neighboring kagome layers. The nature (charge, quantum numbers etc.) of this many-body state is hitherto unknown. Does the magnetic field directly couple to the collective mode, like in a superconductor, or to the single-particle electron states it is made of? The latter seems supported by the effective charge of $1 \times e$ in the flux of Eq. (1). In this context Guo *et al.* point out that the response to field tilt closely resembles commensurability oscillations in layered superconductors and that even in superconductors effects may sometimes be governed by a flux quantum h/e, as opposed to $h/(2e)$.

The onset temperature and angular sensitivity of the oscillations match previous observations of switchable chiral transport, anomalous Nernst and Hall effects, μSR and

NMR anomalies, all emerging near T'. A crucial challenge for future experiments is therefore to exploit whether there are more direct links between these phenomena and, whether the oscillatory component of the current flows in the bulk or the surface.

Within the broader context of correlated quantum matter, this work lends significant support to the view that long-range electronic coherence can develop in mesoscopic samples that are neither superconducting nor governed by the ballistic propagation of single-electron wave packets. In addition, they impose clear constraints on microscopic models of the kagome metals and indicate novel ground states capable of macroscopic interference. More generally, it asks how quantum interference - traditionally associated with superconductors or ballistic electrons - can occur in a metallic, interacting, charge-ordered many-body system.

References

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