Kagome metals

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A magnetic impurity sets off ripples in a kagome superconductor

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The role of magnetic impurities in shaping superconductivity and electronic order in kagome metals remains unresolved. Now, a study reveals anisotropic Kondo resonances intertwined with the superconducting gap in a magnetically doped kagome superconductor.

The interaction between a localized magnetic impurity and conduction electrons remains a central and actively studied research topic in condensed matter physics[1]. This interaction can produce the Kondo effect, in which conduction electrons effectively screen the magnetic moment impurity and cause a characteristic resonance near the Fermi level, which can be observed at low temperatures[2]. The situation becomes more intriguing when the host material is superconducting. In such a scenario magnetism can compete with, suppress, or locally reshape the superconducting state. Kagome metals, where multiple quantum phases can coexist in close proximity, provide a promising platform for exploring such interplay. Writing in *Nature Physics*, Zichen Huang and colleagues report a Kondo-like resonance in dilute Cr-doped CsV_3Sb_5, where Cr atoms substitute V sites[3]. The magnetic dopant was also found to modify the superconductivity of CsV_3Sb_5 (Fig. 1).

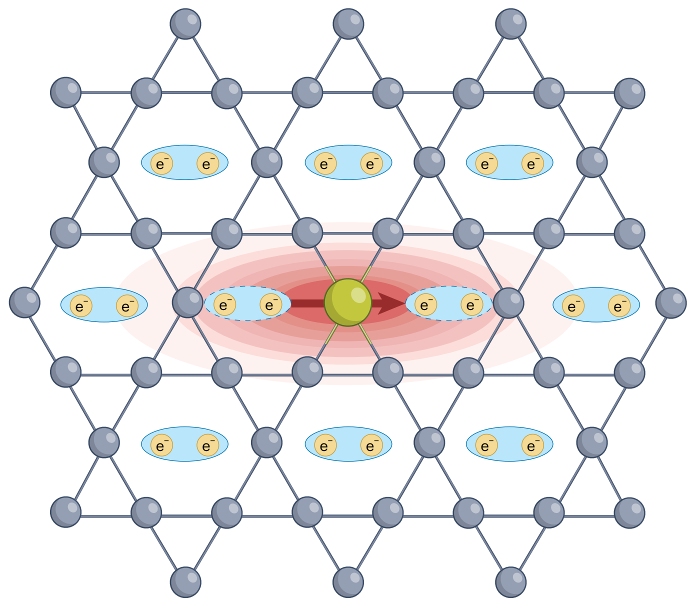

Fig. 1 | The interplay between local magnetic impurity and superconductivity in a kagome metal. Schematic of the kagome lattice formed by the V atoms (grey colour) in CsV_3Sb_5. The green atom with the red arrow represents the magnetic impurity (Cr). The red background in the middle represents a simplified version of the anisotropic impurity-induced Kondo resonance. Cooper pairs are shown around the impurity, with dashed outlines marking their local modification near the magnetic impurity.

In the past few years, kagome metals have attracted considerable interest because of their unique lattice geometry, which naturally leads to various interesting electronic band structure features, namely dispersionless bands (often called flat bands), Dirac points, and divergences in the density of state, known as Van Hove singularities[4]. If present near the Fermi level, the flat band or the Van Hove singularities can enhance correlation effects and make kagome systems highly susceptible to various ordering phenomena. Recent studies have uncovered a wide range of phenomena in kagome metals, including magnetic frustration, charge-density-wave order, superconductivity, anomalous Hall responses, and topological Chern magnetism, among others[4,5].

CsV_3Sb_5 is reported to host charge-density-wave order at high temperatures and superconductivity at low temperatures[6]. The Cr-based sister compound $CsCr_3Sb_5$, in which V is fully replaced by Cr atoms, hosts antiferromagnetic order below 55 K (ref. 7). Partial substitution of V by Cr therefore provides a controlled method to introduce local magnetic moments, which makes Cr-doped CsV_3Sb_5 an excellent platform for examining Kondo physics and studying the interactions between magnetic impurities, charge density waves and superconducting states.

The team performed low temperature scanning tunnelling microscope-based measurements and observed a characteristic resonance peak in the differential conductance (dI/dV, where I is the tunnelling current and V is the bias voltage) spectra near the Fermi level in dilute Cr-doped CsV_3Sb_5. This feature is absent in the pristine compound, which indicates that its origin is tied to the magnetic impurity. The characteristic line shape, temperature-dependent broadening, and magnetic field-induced splitting of the peak, along with theoretical support, point to a Kondo resonance origin. The real-space distribution of the resonance near the impurity, as captured by scanning tunnelling microscopy, is also intriguing, with the resonance forming anisotropic, ripple-like features that propagate along specific lattice directions and break local mirror symmetries rather than remaining isotropic.

The superconducting state of $CsV_{3-x}Cr_xSb_5$ also evolves with the Cr doping. For low Cr concentrations, where the Kondo resonance is observed, both the superconducting gap depth and the coherence peak heights are enhanced. This suggests a possible interaction between the magnetic impurity and Cooper pairs, which are pairs of electrons responsible for superconductivity. At higher doping levels, long-range magnetic order emerges and superconductivity is suppressed. This system therefore provides a controlled platform to explore the coupling between magnetism and superconductivity in a kagome metal.

Another recent study by Yubing Tu and colleagues, also published in *Nature Physics*, on the same topic of Cr doping on CsV_3Sb_5, reported that Cr substitution on the V site introduces local magnetic moments and shows signatures of Kondo physics with anisotropic nature in real space[8]. Although the two studies have some similarities in the experimental observations, there are nevertheless some differences in interpretation.

Huang and colleagues covered a broad range of Cr-doping evolution, from dilute impurities to higher substitution levels, and discuss how charge-density-wave order, Kondo screening, and superconductivity evolve with the doping concentration. The work by Tu and colleagues, however, is primarily focused on the dilute-impurity limit, using isolated Cr dopants as local probes of the Kondo resonance and its spatial anisotropy. Moreover, Huang and colleagues attribute the anisotropy of the Kondo resonance mainly to antiferromagnetic coupling and frustration between Cr-induced moments and neighbouring V states; whereas Tu and colleagues emphasize a connection between the symmetry-broken Kondo pattern and an underlying electronic chirality associated with orbital loop-current order.

The findings reported by Huang and colleagues establish Cr-doped CsV_3Sb_5 as a sensitive platform to study how local magnetism, superconductivity, and charge order interact. At the same time, the microscopic origin of the anisotropy might need future work to determine whether the observed patterns are governed primarily by impurity-induced magnetic frustration, by pre-existing electronic chirality, or by other factors as yet unknown.

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Competing interests

The author declares no competing interests.