Superconductivity in $YbRh_2Si_2$

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Cooper pairing of electrons to form a superconductor can occur via multiple mechanisms [1]. The well-established phonon-mediated pairing in conventional superconductors, such as Al and Nb, results in spin-singlet pair wavefunction that has uniform phase over the Fermi surface. Alternative mechanisms, such as superconductivity driven by spin fluctuations, can lead to both spin-singlet and spin-triplet pairs with complex structures in momentum space. Such unconventional pairing is understood to be required for high temperature superconductivity; moreover some of the spin-triplet superconductors are predicted to have exotic topological properties [2]. There are numerous unconventional superconductors among heavy-fermion metals, however the precise pairing state is rarely known unambiguously.

The canonical heavy-fermion metal $YbRh_2Si_2$ hosts both antiferromagnetic and ferromagnetic fluctuations [3]. It orders antiferromagnetically at 70 mK, but doping allows to tune the magnetism across two antiferromagnetic and one ferromagnetic phase [4]. Evidence for superconductivity and nuclear magnetism below 2 mK have been reported recently from a study of magnetic properties of $YbRh_2Si_2$ [5]. Transport measurements in this temperature regime are challenging and I will report on novel SQUID-based techniques we have developed and applied to probe high-quality single crystals of $YbRh_2Si_2$ and microstructures machined from such crystals using focussed ion beam. We observe unambiguous signatures of superconductivity, such as quantised persistent currents. A complex phase diagram emerges in magnetic field, demonstrating interplay between superconductivity and magnetism. The observed superconductivity beyond Pauli limit and distinct transport regimes, that potentially represent different superfluid phases, point towards unconventional spin-triplet superconductivity driven by the ferromagnetic fluctuations. This opens an intriguing possibility that $YbRh_2Si_2$ is a crystalline topological superconductor, a sought-after material with promising applications in quantum information processing.

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