John Saunders

Department of Physics, Royal Holloway University of London

Quantum materials into the microkelvin regime

The study of quantum materials at the ultralow temperatures is replete with scientific opportunities, and new technical challenges. Significant progress is being made in using helium in two dimensions to realize quantum materials. These include: 2D Fermi liquids; Wigner-Mott-Hubbard transition; putative quantum spin liquid and 2D frustrated magnetism; heavy fermion Kondo breakdown quantum criticality; 2D intertwined density wave and superfluidity. Furthermore there is a renewed scientific impetus to study superfluid ^{3}He. This p-wave superfluid is the only firmly established topological "superconductor". The gift of Nature is that is has both chiral and time reversal invariant phases, with distinct topology. Technical innovations have enabled its study under precisely engineered nanoscale confinement, on length scales of order the superfluid coherence length. Using such confinement as a control parameter, allows sculpture of new superfluid states, and the engineering of hybrid nanostructures. This opens the study of topological mesoscopic superfluid ^{3}He and the characterization of the emergent excitations arising from bulk-surface/edge correspondence.

On the other hand new frontiers are opening up in the area of strongly correlated electron systems. For example we have demonstrated the ability to cool a 2D electron gas to 1 mK and below, with the promise to investigate correlation effects in semiconductor nanostructures and devices. The prospect of studying of quantum critical metallic systems to lower temperatures than hitherto explored is also of interest. Our recent transport measurements on the heavy fermion $YbRh_2Si_2$ as a function of magnetic field demonstrate the onset of superconductivity at low mK temperatures, with several novel features: interplay of superconductivity with electro-nuclear magnetism; anisotropy of the superconductivity; possible multiple superconducting phases.