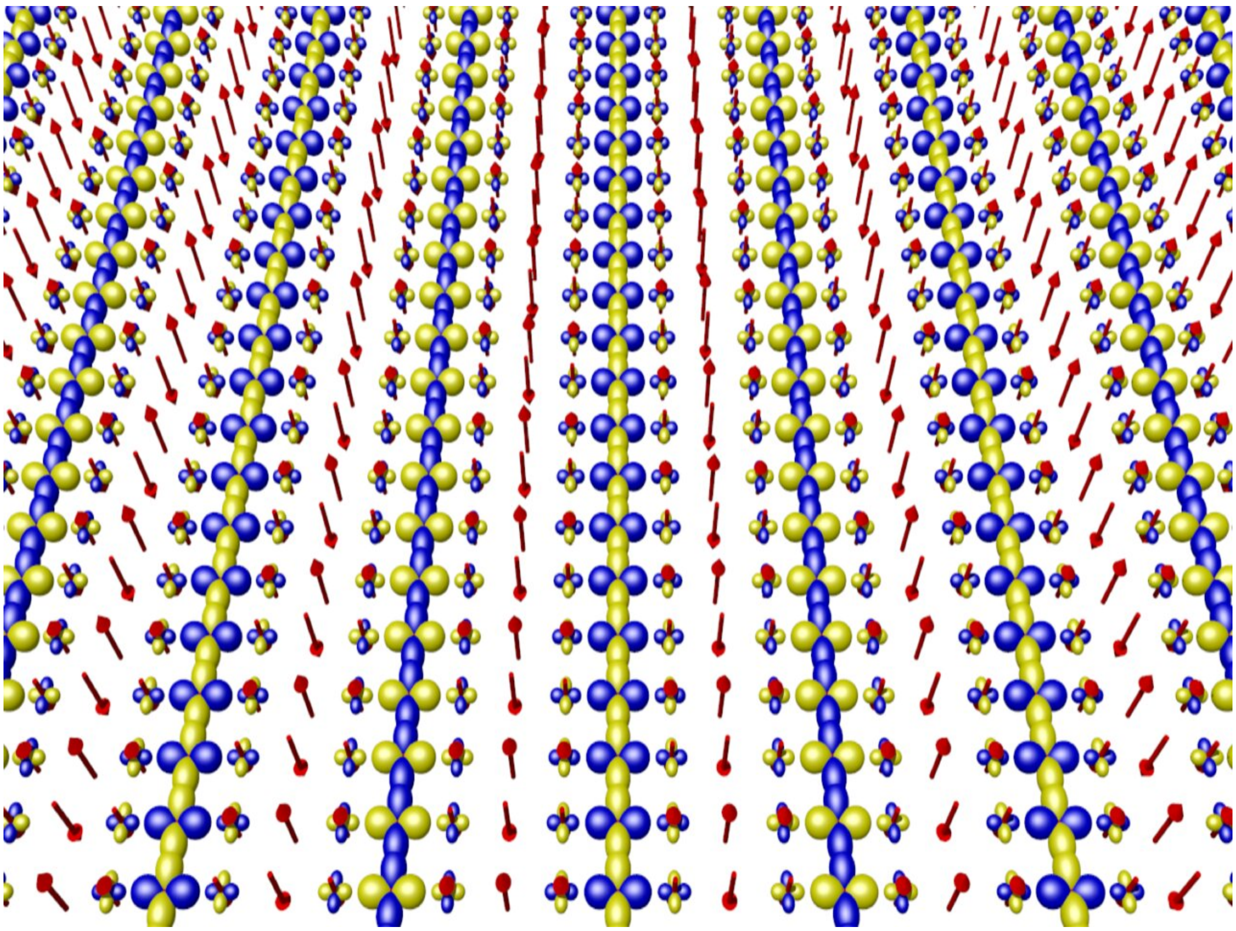
Discovery of field-induced pair density wave state in high temperature superconductors

June 12 2019



Superconductors are quantum materials that are perfect transmitters of electricity and electronic information. Presently, cuprates are the best candidate for highest temperature superconductivity at ambient pressure, operating at approximately -120 °C. Improving this involves understanding competing phases, one of which has now been identified. Credit: MPI CPfS, artist credit to K. Fujita, Brookhaven National Lab

Superconductors are quantum materials that are perfect transmitters of electricity and electronic information. Although they form the technological basis of solid-state quantum computing, they are also its key limiting factor because conventional superconductors only work at temperatures near -270 °C. This has motivated a worldwide race to try to discover higher temperature superconductors. Materials containing CuO_2 crystal layers (cuprates) are, at present, the best candidate for highest temperature superconductivity, operating at approximately -120 °C. But room temperature superconductivity in these compounds appears to be frustrated by the existence of a competing electronic phase, and focus has recently been on identifying and controlling that mysterious second phase.

Superconductivity occurs when electrons form pairs of opposite spin and opposite momentum, and these "Cooper pairs" condense into a homogeneous electronic fluid. However, theory also allows the possibility that these electron pairs crystallize into a "pair density wave" (PDW) state where the density of pairs modulates periodically in space. Intense theoretical interest has emerged in whether such a PDW is the competing phase in cuprates.

To search for evidence of such a PDW state, a team led by Prof. JC Seamus Davis (University of Oxford) and Prof. Andrew P. Mackenzie (Max Planck Institute CPfS, Dresden) with key collaborators Dr. Stephen D. Edkins and Dr. Mohammad Hamidian (Cornell University) and Dr. Kazuhiro Fujita (Brookhaven National Lab.), used high magnetic fields to suppress the homogeneous superconductivity in the cuprate superconductor $Bi_2Sr_2Ca_2CuO_2$. They then carried out atomic-scale visualization of the electronic structure of the new field-induced phase. Under these circumstances, modulations in the density of electronic states containing multiple signatures of a PDW state were discovered. The phenomena are in detailed agreement with theoretical predictions for a field-induced PDW state, implying that it is a pair density wave which competes with superconductivity in cuprates.

This discovery makes it clear that in order to understand the mechanism behind the enigmatic high temperature superconductivity of the cuprates, this exotic PDW state needs to be taken into account, and therefore opens a new frontier in cuprate research.

More information: S. D. Edkins et al, Magnetic field–induced pair density wave state in the cuprate vortex halo, *Science* (2019). DOI: 10.1126/science.aat1773

Provided by Max Planck Society