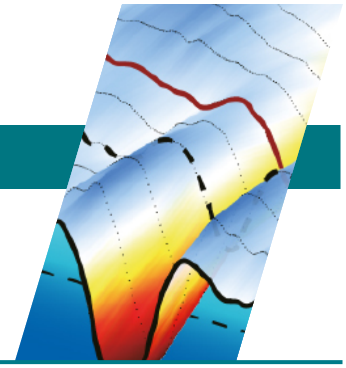
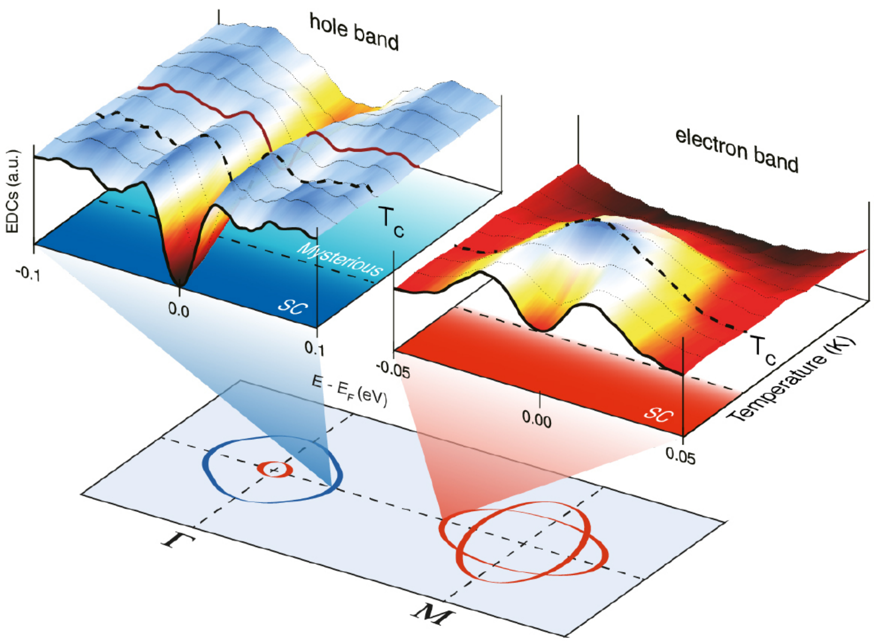


Interlayer Coupling Drives Mysterious Phase Transition



In a layered superconductor, a band gap (represented by the central valleys in the plots above) persisted above the superconducting transition temperature (dotted black line) for the hole band (left). The gap disappeared above the transition temperature for the electron band (right). This band-selective feature provided an important clue to the origins of a mysterious phase transition in the material.

Scientific Achievement

Using the Advanced Light Source (ALS), researchers found that a mysterious phase transition in an iron-based superconductor is driven by interactions between the material's 2D layers.

Significance and Impact

The results counter the assumption that interlayer coupling is negligible in such materials, suggesting instead that the interactions can be an effective way to tune superconductivity.

Heterostructured superconducting systems

The interleaving of distinct two-dimensional layers—the building blocks of what are known as hetero-structures—can lead to the emergence of unexpected, rich physics not observed in the constituent materials alone. Based on this, researchers have been busily shuffling the deck in search of layer combinations that will yield exotic physical properties. In particular, a heterostructure consisting of strongly correlated electron systems might produce novel effects, including drastically boosted superconductivity.

The iron-based superconductor, Sr_2VO_3FeAs, is a heterostructure of iron arsenide (SrFeAs) and a transition-metal oxide ($SrVO_3$). The superconducting transition temperature (T_C) is about 30 K, but an unusual phase transition occurs at about 150 K that cannot easily be explained within conventional theoretical frameworks. Here, using band structures revealed through angle-resolved photoemission spectroscopy (ARPES), researchers concluded that the mysterious phase originates from surprisingly strong proximity-induced interactions between neighboring layers.

Broken symmetry in correlated systems

Strongly correlated electron systems (i.e., where strong interactions between electrons must be accounted for and not averaged out) often exhibit a variety of self-organized forms of broken symmetry—localized variations in spin direction, charge distribution, or bond angle, for example. In correlated itinerant-electron systems, exemplified by doped copper- and iron-based superconductors, multiple many-body instabilities promote a rich and complex landscape of electronic orders. The resulting broken symmetries register their footprints in the electronic structure through features such as band folding, band splitting, and band-gap opening. Investigating these footprints in turn helps characterize the different phases—what type of phase transition occurs, what kind of interaction is involved, and how the system lowers its energy across the phase transition.

At 150 K, an intriguing phase transition in Sr_2VO_3FeAs has been clearly indicated by anomalies in temperature-dependent measurements of resistivity and specific heat. Despite its clear thermodynamic signature, the phase transition cannot be described by conventional types of ordering reported in other iron-based superconductors.

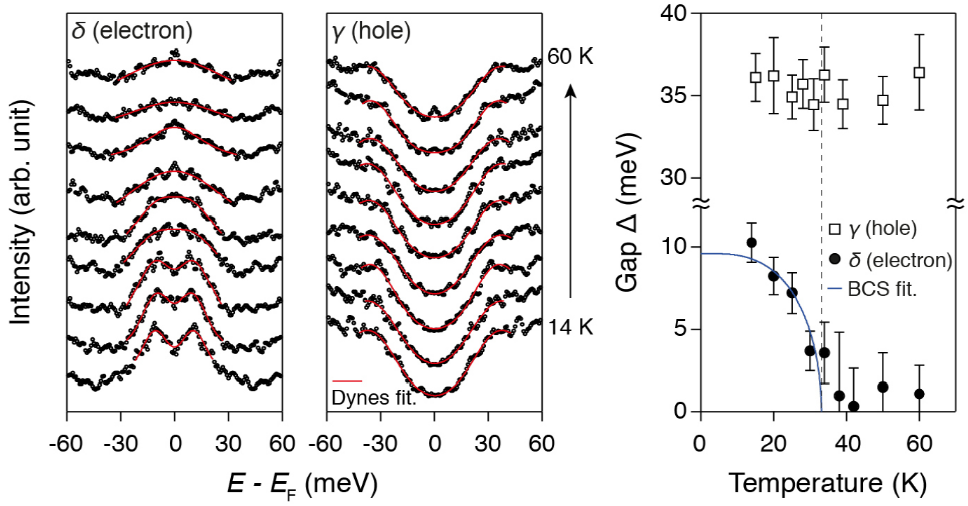
Band-selective gap opening

To better understand this mysterious phase, a team of researchers investigated the low-energy electronic structure of Sr_2VO_3FeAs using ARPES, a powerful technique for probing electronic structures in detail. At ALS Beamlines 10.0.1 and 4.0.3, the microfocused soft x-ray light enabled the systematic study of tiny samples at a wide range of temperatures, photon energies, and momenta. The experiments revealed a discrepancy between electron and hole bands. Below T_C, the spectra taken at both bands show a clear gap opening—an indicator of superconductivity. Above T_C, however, only the hole band gap remained open.

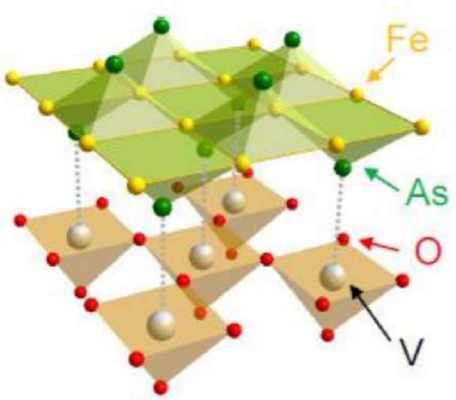
The role of proximity coupling

Analysis of this band selectivity, together with the observation of some unusual magnetoresistance behavior, suggested that proximity coupling between itinerant Fe electrons in the SrFeAs layers and localized V spins in neighboring $SrVO_3$ layers stabilizes the exotic phase, which may serve as a distinct precursor state for unconventional superconductivity.

In general, proximity coupling is weaker than other interactions in generating particular electronic states. However, the work here demonstrates that such interlayer interactions, resulting from the subtle balance between different pairings of correlated electron systems, can be a productive tool for realizing and understanding novel exotic states in heterostructures.



Symmetrized (mirrored) energy distribution curves (EDCs) for electron (left) and hole (middle) bands, respectively, obtained at various temperatures using ARPES data. The far-right panel shows the gap sizes of each band as a function of temperature. The dashed line indicates the T_C of the sample. The hole band gap remains open even above T_C, while the electron band gap gets smaller and finally closes.



Crystal structure of the layered superconductor, Sr_2VO_3FeAs. The Fe (top) and V (bottom) planes can be coupled through the As atoms, positioned below the center of Fe_4 units and above the V atoms. For clarity, the Sr atoms have been omitted.

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Publications: S. Kim, J.M. Ok, H. Oh, C. Kwon, Y. Zhang, J.D. Denlinger, S.-K. Mo, F. Wolff-Fabris, E. Kampert, E.-G. Moon, C. Kim, J.S. Kim, and Y. Kim, "Band-selective gap opening by a C_4-symmetric order in a proximity coupled heterostructure Sr_2VO_3FeAs," *PNAS* **118**, e2105190118 (2021), doi:10.1073/pnas.2105190118.

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