Basic Research

Spectroscopic Evidence for an Additional Symmetry Breaking in the Nematic State of FeSe Superconductor

In iron-based superconductors, FeSe has the simplest crystal structure which consists solely of the basic building block, the FeSe layers, that dictates the superconductivity. It undergoes a structural phase transition at around 90 K to enter a nematic state but without a long-range magnetic order. So, FeSe is an ideal system to investigate the nematicity and superconducting mechanism in iron-based superconductors. It represents a unique system that superconductivity and nematicity coexist in the superconducting state, giving rise to its distinct electronic structure and superconducting gap structure. Many new superconductors have been derived from FeSe with enhanced superconductivity, including $K_xFe_{2-y}Se_2$, (Li,Fe)OHFeSe, single-layer FeSe/$SrTiO_3$ films and so on. Determination of the electronic structure is essential to understanding the physical properties and superconductivity mechanism in bulk FeSe and its many derivatives. Both theoretical and experimental studies so far have provided a picture that FeSe consists of only one hole-like Fermi surface around the Brillouin zone center in its nematic state. All the experimental and theoretical understandings of FeSe have been based on the single Fermi surface picture.

Recently, Dr. LI Cong and Prof. ZHAO Lin with Prof. ZHOU Xingjiang's group at the National Laboratory for Superconductivity, Institute of Physics (IOP), Chinese Academy of Sciences (CAS), found a new Fermi surface structure in FeSe superconductor, in

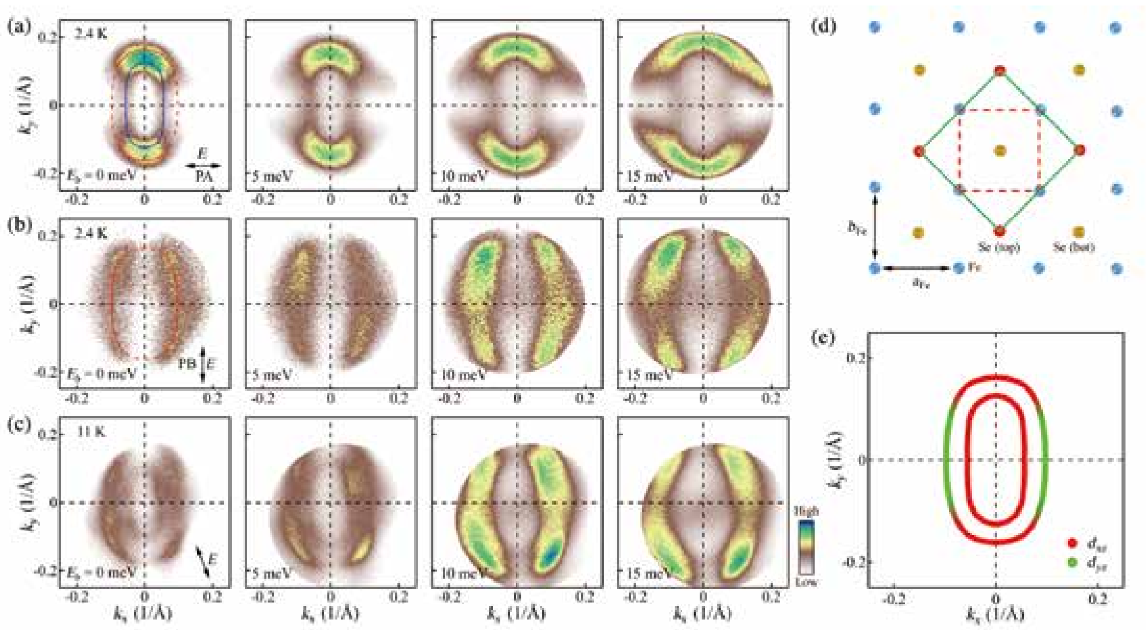

Figure 1: The discovery of double holelike Fermi surface structure around the Brillouin zone center in FeSe. (Image by ZHOU Xingjiang's group)

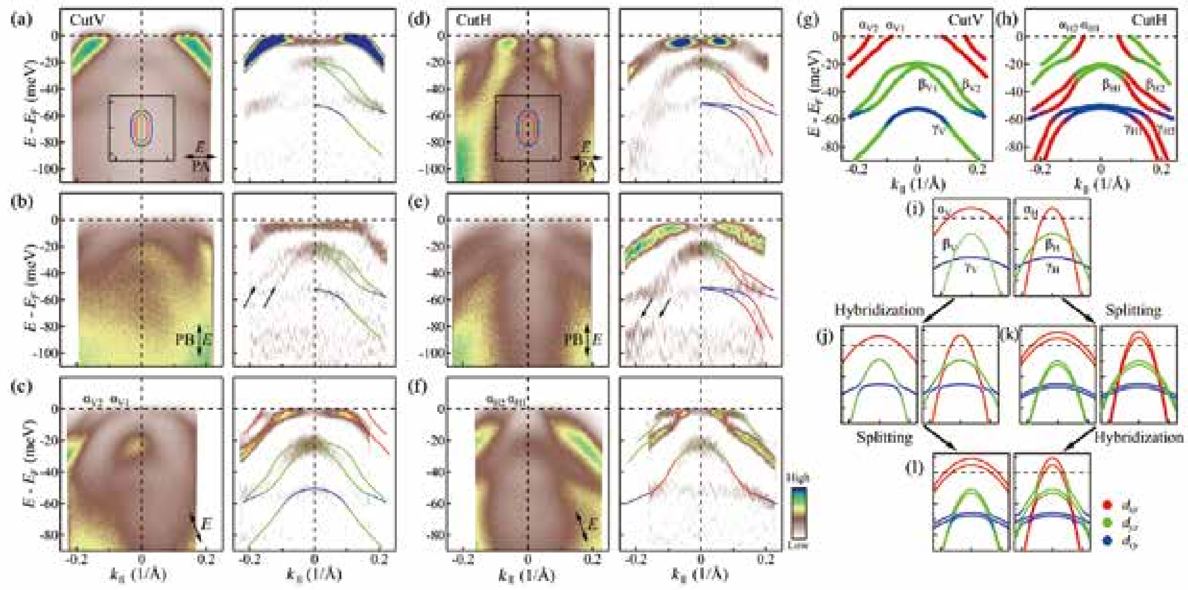

Figure 2: Band structure of single-domain FeSe along high-symmetry cuts and their orbital nature. (Image by ZHOU Xingjiang's group)

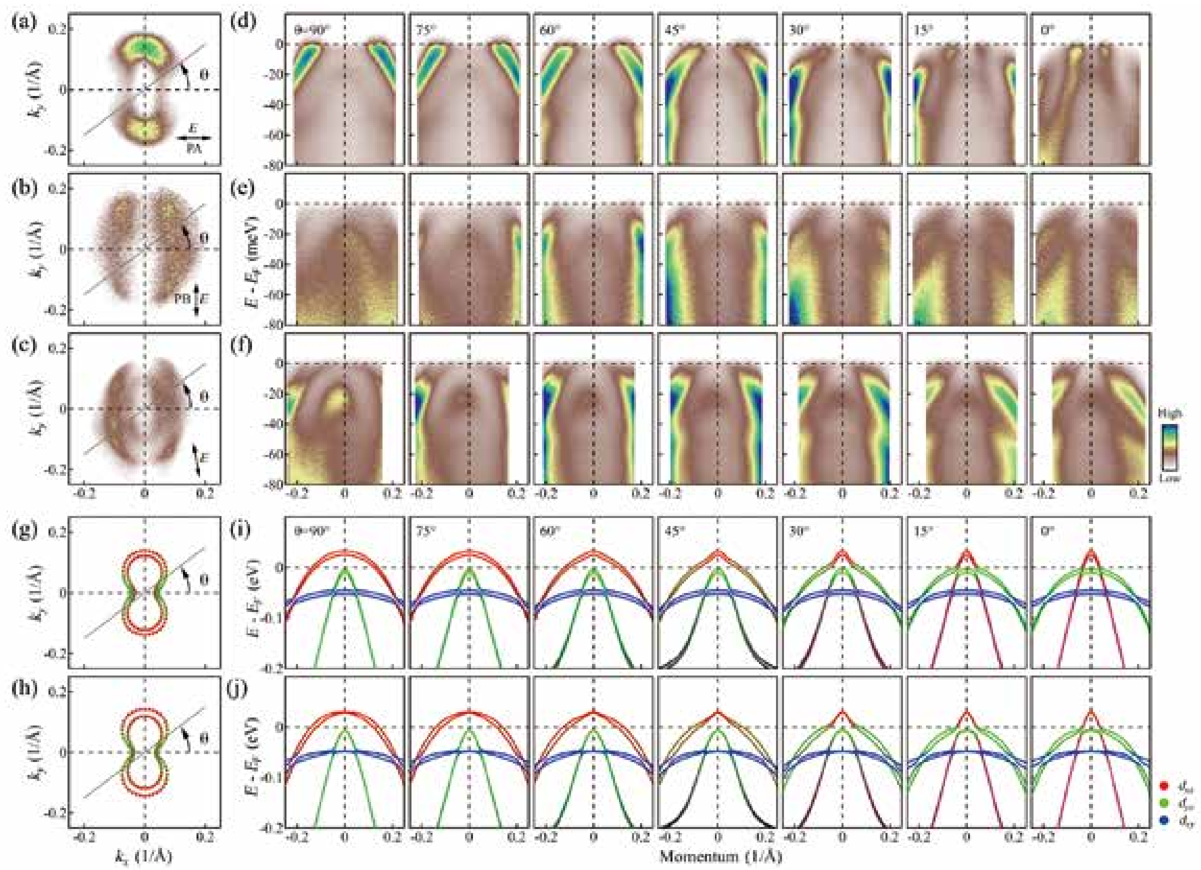

Figure 3: Calculated Fermi surface and band structure of FeSe and their comparison with the measured results (Image by ZHOU Xingjiang's group)

cooperation with their IOP colleagues Dr. WU Xianxin, Dr. WANG Le, Prof. SHI Youguo, Prof. HU Jiangping and Prof. XIANG Tao. Using the latest generation of electron energy analyzer based on time-of-flight laser-ARPES, and combining with the theoretical calculation, they revealed that in FeSe, there exists an extra hidden order in parallel with the nematic order.

By performing latest-generation high resolution laser-based ARPES measurements on FeSe, they discovered for the first time that there are two hole-like Fermi surface sheets around the Brillouin zone center in single domain bulk FeSe. The inner Fermi surface mainly consists of d_{xz} orbital, while the outer Fermi surface consists of d_{xz} and d_{yz} orbitals (Figure 1). The measurement of the band structure indicates that three bands around the Brillouin zone center exhibit band splitting (Figure 2). The further theoretical analysis shows that it is impossible to induce the observed double Fermi surface structures and corresponding band splitting if only considering nematic order and orbital hybridization. An extra new order besides the nematic order should be present that breaks inversion symmetry or time reversal symmetry to cause the lifting of the spin degeneracy and induce double Fermi surfaces and band splitting (Figure 3).

The newly discovered Fermi surface structure and band splitting in the nematic state of FeSe asks for reexamination of the previous theoretical and experimental understanding of FeSe and will stimulate further efforts to identify the hidden order in the nematic state of FeSe. This study entitled "Spectroscopic Evidence for an Additional Symmetry Breaking in the Nematic State of FeSe Superconductor" was published in *Physical Review X*.

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