Competition between Ordered States and Unconventional Superconductivity

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Many of the unconventional superconductors have complex phase diagrams, where the superconducting phase is often adjacent, or partially overlaps with an ordered state. Two best examples are cuprates and pnictides high-temperature superconductors, where superconductivity partially coexists with pseudogap and antiferromagnetic state respectively. Understanding the relation between superconductivity and those other states may be the key to uncover the pairing mechanism in those exciting systems.

Pseudogap state in cuprates is one of most interesting topics in modern condensed matter physics. This state is characterized by anisotropic energy gap that leads to seemingly disconnected segments of the Fermi surface, so called “Fermi arcs.” The relationship between the pseudogap and superconductivity is one of the central issues in physics of cuprates. One of the leading theories explaining it is so called "pre-formed" pair scenario, where pseudogap is thought to be a state of paired electrons that lack the long-range coherence. Another class of theories attributes the pseudogap to an ordered state that would naturally compete with superconductivity. By studying the spectral weights associated with pseudogap and superconductivity using Angle Resolved Photoemission Spectroscopy (ARPES) we found that there is a direct correlation between the loss of the low energy spectral weight due to the opening of the pseudogap and a decrease of the spectral weight associated with superconductivity as a function of momentum and doping. High accuracy data lead us to conclude that the pseudogap competes with the superconductivity by depleting the spectral weight available for pairing in the region of momentum space, where the superconducting gap is largest. We also conducted detailed studies of the temperature dependence of the spectral weight at the chemical. We found evidence for a spectroscopic signature of pair formation and demonstrated that in a region of the phase diagram commonly referred to as the “pseudogap,” two distinct states coexist: one that persists to an intermediate temperature Tpair and a second that extends up to T*. The first state is characterized by a doping independent scaling behavior and is due to pairing above T_c, but significantly below T*. The second state is the “proper” pseudogap - characterized by a “checker board” pattern in STM images, the absence of pair formation, and is likely linked to Mott physics of pristine CuO_2 planes.

The newly discovered iron arsenic high temperature superconductors exhibit particularly rich and interesting phase diagrams. In $Ba(Fe_{1-x}Co_x)_2As_2$ the simultaneous structural/magnetic phase transition that occurs at elevated temperature in the undoped material, splits and is suppressed by carrier doping, and superconductivity emerges at higher doping. Superconductivity exists with apparent equal ease in the orthorhombic / antiferromagnetic (AFM) state as well as in the tetragonal state that has no long-range magnetic order. We found that dramatic changes in the Fermi surface coincide with the onset of superconductivity in electron-doped $Ba(Fe_{1-x}Co_x)_2As_2$. The presence of the AFM order leads the appearance of the petal-like hole pockets at the Fermi level. These hole pockets vanish (undergo a Lifshitz transition) at the onset of superconductivity. In the presence of the petal-like hole pockets superconductivity is fully suppressed, while in their absence the two states can coexist.