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Atomic-scale Visualization of Electronic Nematicity and Cooper Pairing in Iron-based Superconductors[1]

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The mechanism of high-temperature superconductivity in the relatively novel iron-based high-T_c superconductors is unresolved, both in terms of how the phases evolve with doping, and in terms of the actual Cooper pairing process. To explore these issues, we used spectroscopic-imaging scanning tunneling microscopy to study the electronic structure of $CaFe_2As_2$ in the antiferromagnetic-orthorhombic 'parent' state from which the superconductivity emerges. We discovered and visualized the now widely studied electronic 'nematicity' of this phase, whose suppression is associated with the emergence of superconductivity (*Science* 327, 181, 2010). As subsequent transport experiments discovered a related anisotropic conductance which increases with dopant concentration, the interplay between the electronic structure surrounding each dopant atom, quasiparticle scattering therefrom, and the transport nematicity has become a pivotal focus of research. We find that substituting Co for Fe atoms in underdoped $Ca(Fe_{1-x}Co_x)_2As_2$ generates a dense population of identical and strongly anisotropic impurity states that are distributed randomly but aligned with the antiferromagnetic a-axis. We also demonstrate, by imaging their surrounding interference patterns, that these impurity states scatter quasiparticles and thus influence transport in a highly anisotropic manner (M.P. Allan et al., 2013). Next, we studied the momentum dependence of the energy gaps of iron-based superconductivity, now focusing on LiFeAs. If strong electron-electron interactions mediate the Cooper pairing, then momentum-space anisotropic superconducting energy gaps $\Delta_i(k)$ were predicted by multiple techniques to appear on the different electronic bands i. We introduced intraband Bogoliubov quasiparticle scattering interference (QPI) techniques for the determination of anisotropic energy gaps to test these hypotheses and discovered the anisotropy, magnitude, and relative orientations of the energy gaps on multiple bands (*Science* 336, 563 (2012)). Finally, the electron-electron interactions generating Cooper pairing are often conjectured to involve bosonic spin fluctuations generated by interband scattering of electrons. We explore the STM signatures of both the interband scattering and the electron-boson coupling self-energy in LiFeAs, and detect the signatures of the electron-boson coupling (M.P. Allan et al., in preparation).

[1]In collaboration with A.W. Rost, T.-M. Chuang, F. Massee, M.S. Golden, Y. Xie, M.H. Fisher, E.-A. Kim, K. Lee, Ni Ni, S.L. Bud'ko, P.C. Canfield, Q. Wang, D.S. Dessau, K. Kihou, C.H. Lee, A. Iyo, H. Eisaki, D.J. Scalapino, A.P. Mackenzie and J.C. Davis