Unveiling the Competing Orders in Cuprate Superconductors

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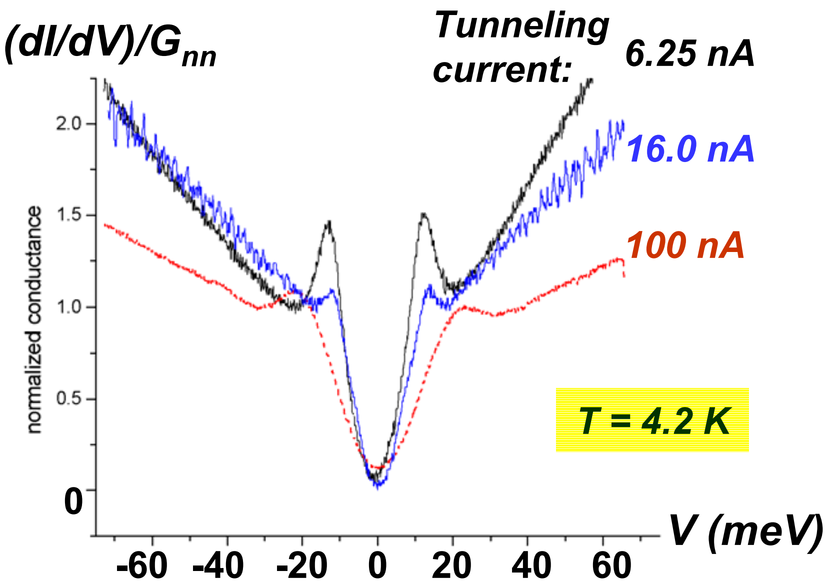
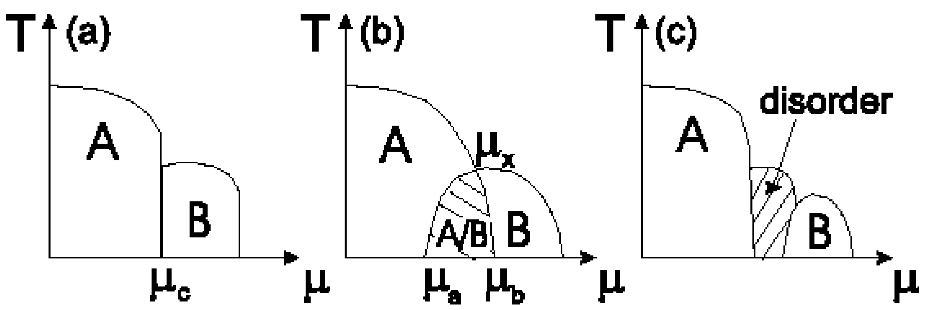
Various puzzling non-universal phenomena in the cuprate superconductors, such as the pairing symmetry, pseudogap, low-energy spin excitations, and spatial homogeneity of quasiparticle spectra, have hindered theoretical progress in unraveling the pairing mechanism for cuprate superconductivity to date. In our recent publications, we have attributed the non-universal phenomena to competing orders in the ground state of the cuprates, and have elaborated this viewpoint. In particular, we have elucidated the presence of a "pseudogap phase", which coexists with superconductivity and can be manifested in forms of disorder-pinned collective modes, in both electron- and hole-doped cuprate superconductors. The top figure is an example of how the pseudogap phase in the infinite-layer electron-doped cuprate $Sr_{0.9}La_{0.1}CuO_2$ is unveiled in the quasiparticle tunneling spectroscopy by suppressing superconductivity with large tunneling currents. The bottom figures illustrate three possible temperature (T) vs. chemical potential (μ) phase diagrams for two competing phases A and B.





(a) First-order critical point or critical line at $\mu = \mu_c$.

(b) A/B phases coexisting between μ_a and μ_b and separated from pure A and B by second-order phase transitions.

(c) A and B separated by a disorder region.

Related publications emanated from this support in 2003:

- N.-C. Yeh, *Highlight* in the Bulletin of Assoc. Asia Pacific Phys. Soc. (AAPPS) Vol. **12**, No. 2, 2-20 (2002). [cond-mat/0210656]
- N.-C. Yeh and C.-T. Chen, Int. J. Mod. Phys. B **17**, 3575 (2003).
- C.-T. Chen and N.-C. Yeh, Phys. Rev. B, in print (2003).
- N.-C. Yeh *et al.*, J. Low Temp. Physics **131**, 435 (2003).

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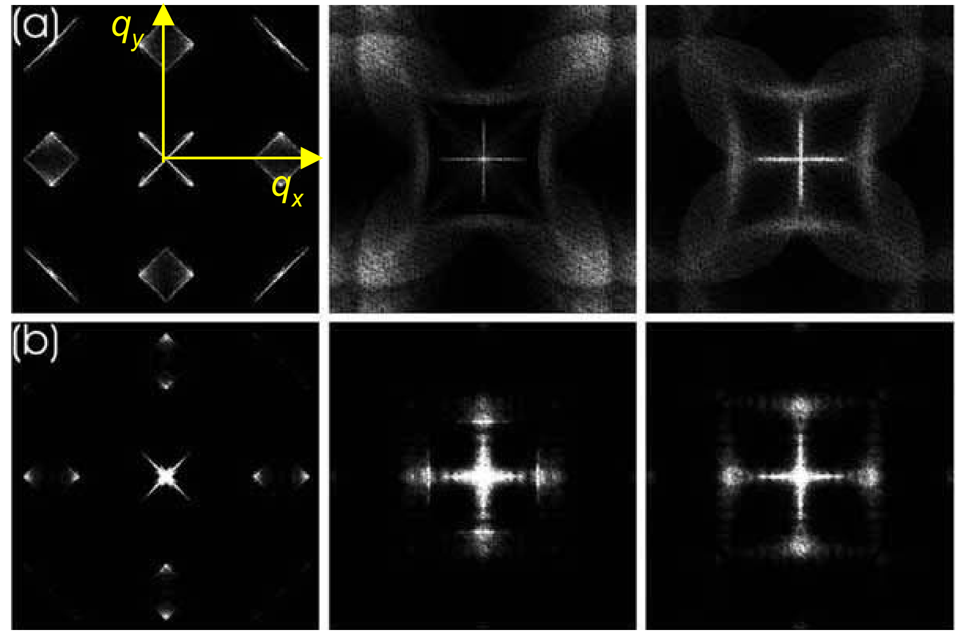
In addition to experimental studies, we have also performed theoretical calculations to investigate how the quasiparticle local density of states (LDOS) of cuprates varies in the presence of competing orders. Our theoretical studies suggest that empirical quasiparticle LDOS taken on highly two-dimensional (2D) cuprates $Bi_2Sr_2CaCu_2O_{8-x}$ (Bi-2212) can be fully accounted for only if we consider the ground state of the cuprates consist of coexisting superconductivity and a competing "pseudogap" phase manifested in the form of disorder-pinned spin-density waves (SDW) or charge-density waves (CDW). The upper figures to the right contrast the temperature-dependent Fourier transformation of the quasiparticle LDOS for a 2D d-wave superconductor under (a) random point-impurity scattering and (b) disorder-pinned SDW. We note that empirical results for $T < T_c$ appear to be consistent with the combination of both (a) and (b), whereas those for $T \geq T_c$ are only consistent with (b). The lower figures reveal the real-space quasiparticle LDOS on a CuO_2 plane with (a) point defects, (b) CDW and (c) SDW.

<u>Trainees involved in this research</u>:

- Graduate students: Ching-Tzu Chen, Andrew D. Beyer, Cameron R. Hughes.
- Undergraduate student: Serena M. Eley.

(T = 0) **(T = 0.75 T_c)** **(T = T_c)**



Tunneling conductance on a (400 x 400) CuO_2 plane:

(point impurities) **(pinned CDW)** **(pinned SDW)**