STM on high-$T_c$ superconductor [Yandazi]

- Result: pairing in Cuprate is highly local
- All cuprates come with Cu-O plane

- From photoemission, for $T > T_c$

\[ \text{underdop} \quad \text{overdop} \]

- Theoretically, Hubbard (to lesser degree $t$-$J$) model is thought to be good description of physics
  - Proposed state is Anderson's RVB. Shown to give d-wave.
  - Not clear if an electron-boson coupling picture is reasonable or not.

- Big question: when (at what $T$) does Cooper pairs form?
- d-wave is very sensitive to surface quality

- Consider $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$+d (easy to cleave)
  - For overdop,
  - get:
    \[ \frac{dI}{dV} \]
  - Strong variation of spectrum across space
This produces inhomogeneous gap map.
- For large enough samples, gap distribution is highly reproducible.
- Length scale of variation ~ 20-30 Å
- Typical plot has 256 x 256 pixels, need ~3 days to take.
- The conductance map becomes almost uniform as energy approaches E₀ (i.e., towards node).
  \[ R = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \]
  \[ b = \text{quasiparticles at nodes are not scattered} \]
- Fourier transform gives interference peaks:

\[ \begin{array}{c}
\text{Interpret as coming from scattering at end of arcs} \\
\text{(highest density of states).}
\end{array} \]
- There are 2-dimensional zero-mode on surface of sample

\[ \begin{array}{c}
\text{Andreev bound state} \\
\text{zero bias peaks appear.}
\end{array} \]
- Similar effect occurs near impurity.

Consider the inhomogeneous gap map, want to know what happens
- Sample om m + heating \[ \rightarrow \] nm expansion.
  But need nm resolution.
  \[ \rightarrow \] Need atom tracking spectroscopy.
- Gaps at different size at low T disappears at different \[ T \].
  (i.e., non-uniform closing of gap).
\[ \text{Repeat heating-cooling reproduces the same gap map, and variation of gap size does not change its length scale as } T \rightarrow T_c \text{ (c.f. coherence length, which diverges as } T \rightarrow T_c). \]

- If we take \( \frac{[dI/dV]_{sc}}{[dI/dV]_N} = R \) across different spots, then we see:
  - different region has different local \( T_c \).

\[ \text{On the overdoped size, the distribution of gaps normalized to mean gap size all look similar.} \]

- For optimally doped sample, the gap size distribution changes very slightly across \( T_c \).

- Found \( \frac{2\Delta}{k_B T_c} = 7.9 \pm 0.2 \) on optimal overdoped side.

- \( \sim 100,000 \) independent measurements.

- The "onset temperature" of Ong, Tom, is about 50% between \( T_c \) & \( T_p \) across doping for optimal overdoped side & phase diagram.

- On underdoped side, the spectra becomes bizarre (doesn't fit well to conventional d-wave).

- In underdoped samples there are also energy-independent interference peaks.
Recall that $R = [dI/dV]_S / [dI/dV]_N$ shows dips left
& right & gap
- May indicate some e⁻—boson coupling.

- $R$

- Found no significant correlation between possible electron—boson coupling & gap size.
  $\Rightarrow$ e⁻—boson pairing is unlikely the cause of local gap inhomogenity.

- Possible effects that affect gap size (correlation strong)
  - Structural features
  - Dopants/impurities, (Cr ~ -0.2)

- $dI/dV$ at $E_F$ for $T > T_c$ correlate negatively with the gap map at low $T$ (Cr ~ -0.7) on optimal— overdoped side
  - Turns out e⁻ excitations give little information while
    hole-like excitation correlate with gap size.
  $\Rightarrow$ electron-hole asymmetry.

- Across $T_c$, the only noticeable change is that at low energy, the quasiparticles are no longer "ignorant" about local
  inhomogeneity.