Enhanced Pairing in the Plaquette-Hubbard Model

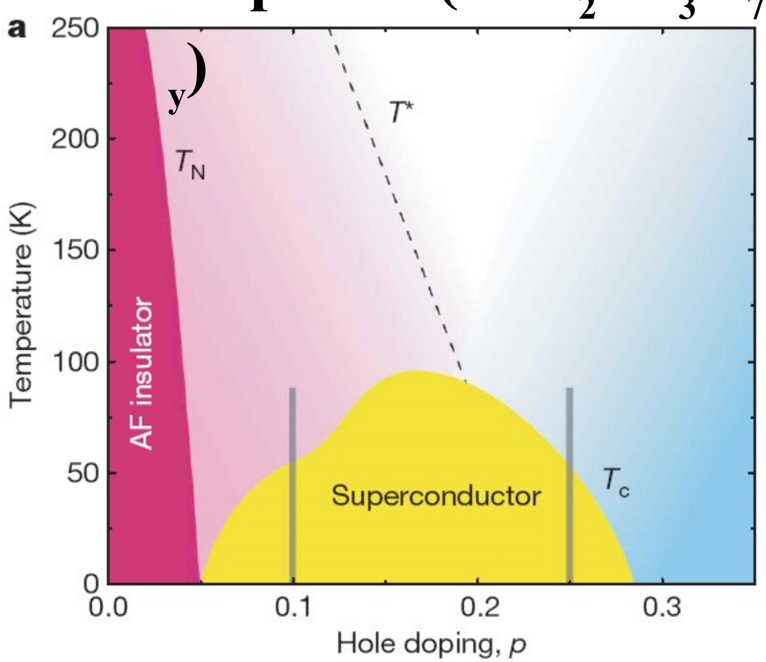
Erez Berg[1], George Karakonstantakis[1], Steve R. White (UCI)[2], Steven A. Kivelson[1]

[1] Stanford University, [2] UC Irvine

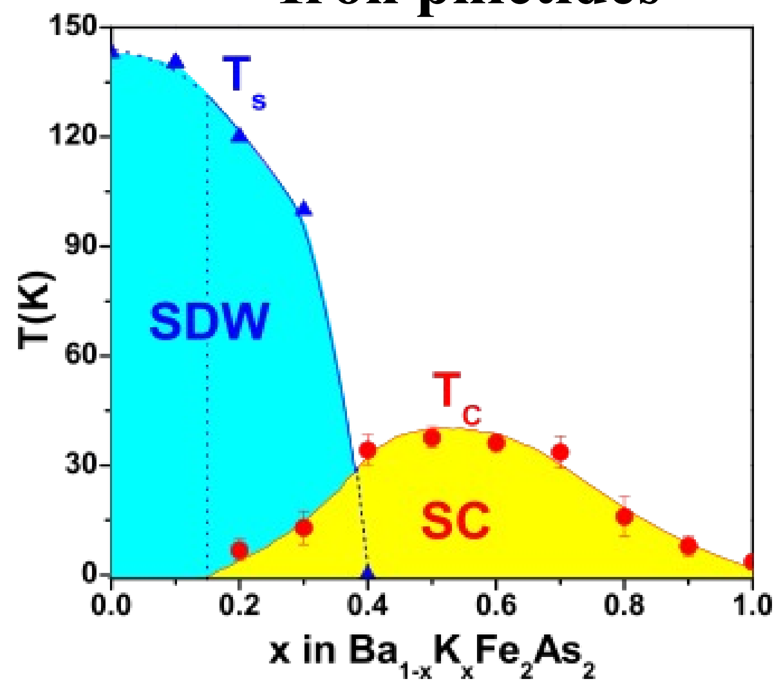
Background: Pairing from repulsive interactions!

- Large U/W – little room to retardation
- Proximity to Mott insulator/magnatically ordered states
- "Unconventional" order parameter and unusual (non-Fermi liquid) normal state

Cuprates ($YBa_2Cu_3O_{7-y}$)

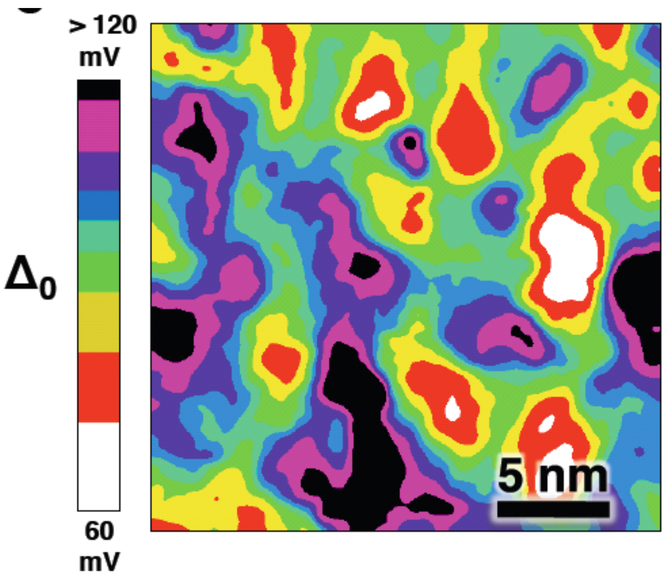


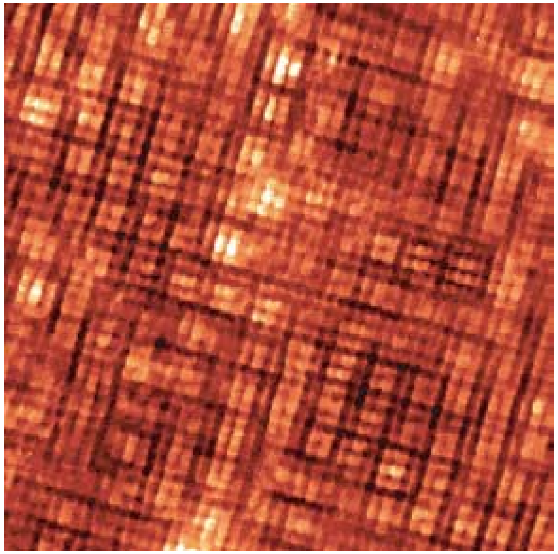
Iron pnictides



Inhomogeneity in HTS

- Inhomogeneities (either extrinsic or intrinsic) are everywhere!
- Tc is surprisingly robust - Short coherence length
- STM experiments:





A. Pushap et al, arXiv (2009)

T. Hanaguri, Nature (2004)

The problem: Recipe for a high Tc superconductor?

Parts of the answer are known:

- on-site U can be good, further-range Culoumb bad
- Optimal Tc – intermediate W/U

Inhomogeneity - good/bad?

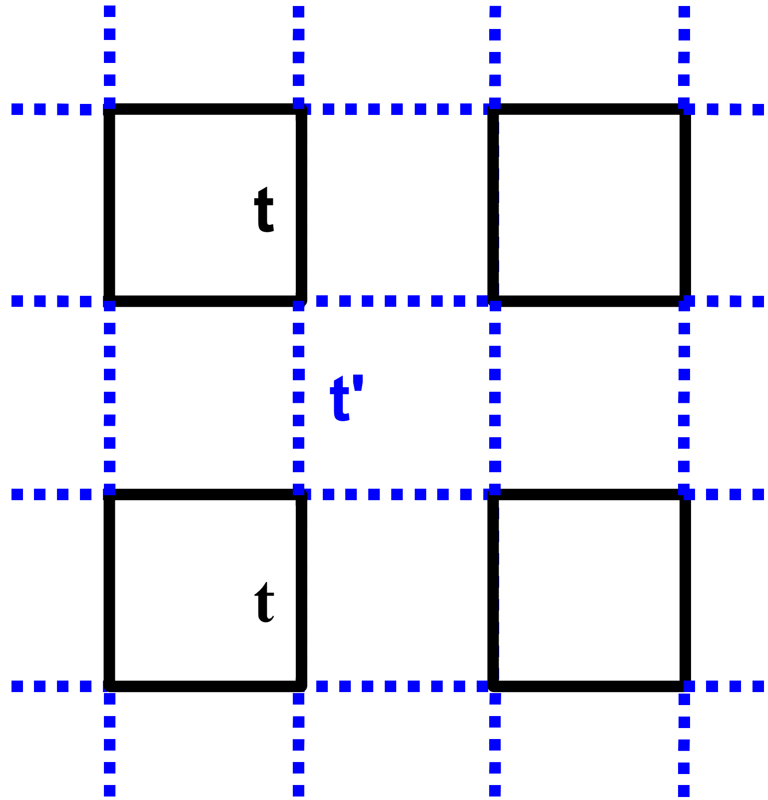
Hubbard Hamiltonian

$$H = -\sum_{\langle i,j\rangle,\sigma} t_{ij}(c^{\dagger}_{i,\sigma}c_{j,\sigma} + \mathrm{H.c.}) + \sum_{i} U_i n_{i,\uparrow} n_{i,\downarrow}$$

"Rules of the game:" Vary t_{ij}, U, keeping max{t_{ij}} $\leq$ t.

Tsai, Yao, Kivelson, Lauchli (20

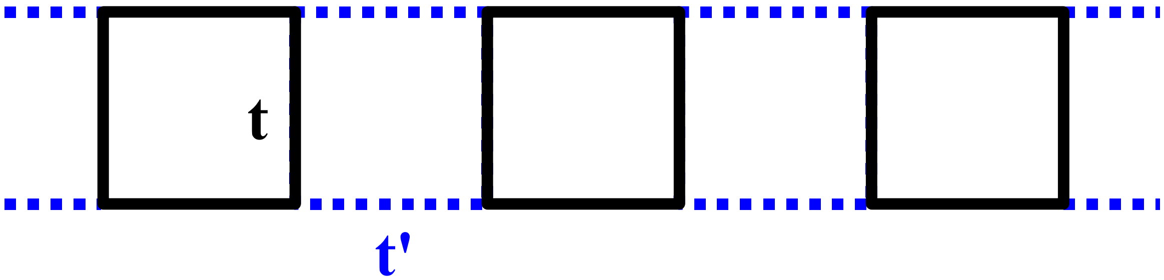
The Plaquette Hubbard model



- The single Hubbard plaquette: d wave-Mott g.s., pair binding for U<4.6t

Altman, Auerbach (2002), Tsai, Kivelson (2006), Yao et al. (2008), Rey et al. (2008), Baruch, Orgad (2009)

The Plaquette Hubbard ladder



- 2-leg Hubbard ladder: spin gap, power-law d-SC correlations, amenable to weak coupling RG, numerical methods (e.g. DMRG)
- T_c = 0! (1D)
- Energy scales characterizing pairing: Δ_s, Δ_{pb}
- Later: the phase stiffness ρ_s

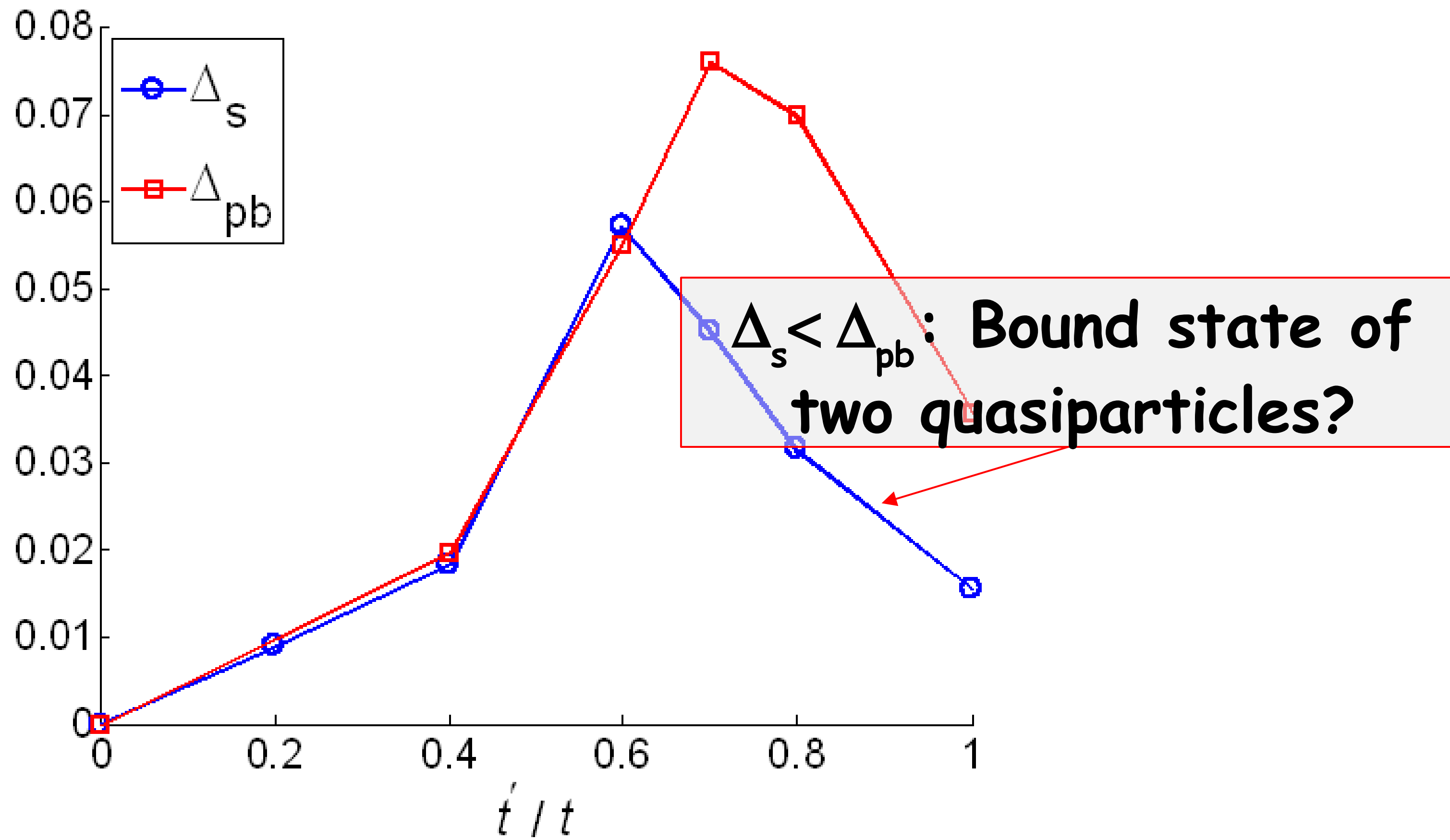
DMRG results

U = 8, n = 0.875

$\Delta_s = (E_{S=1} - E_{S=0}) / 2 \qquad \Delta_{pb} = (2E_{N+1} \quad E_N - E_{N+2}) / 2$

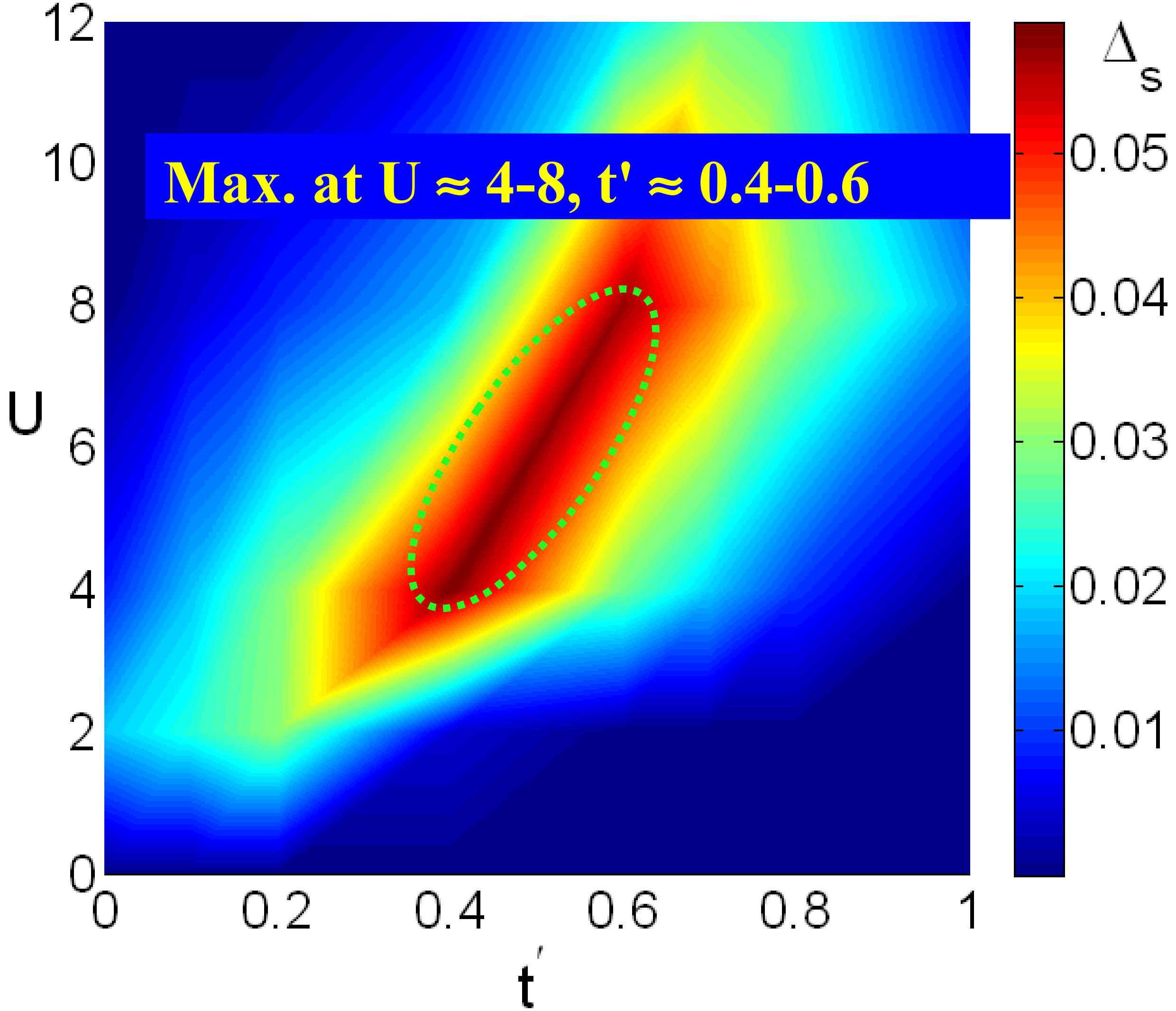
Extrapolated to the $L \rightarrow \infty$ limit (sizes up to 64x2)

All energies in units of t



Results

Δ_s for n = 0.875 vs. t', U



Maximum pairing for $t' < 1$!

What about phase ordering?

Phase ordering scale

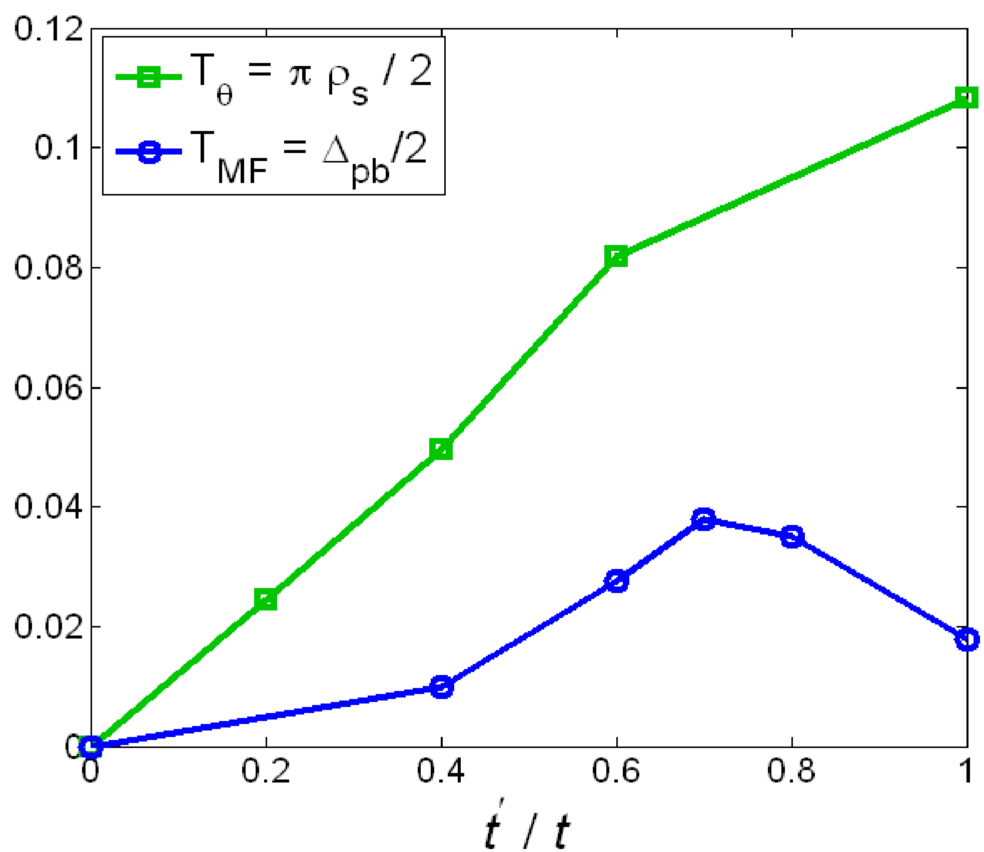
- A rough estimate of the "phase ordering scale":

$$T_\theta = \pi \rho_s / 2$$

Where $\rho_s = \partial^2 E/\partial\phi^2 (L/2a)$ (a – lattice constant)

- Compare to the "pairing scale":
$$T_{MF} = \Delta_{pb} / 2$$

$$\boldsymbol{T_\theta > T_{MF}\ !}$$



Conclusions

- Pairing in the "Plaquette Hubbard ladder":
  - Optimized pairing for $t'/t \approx 0.4–0.6$, $U \approx 4–8$
  - Large phase stiffness

- What causes the pairing enhancement?
- Other "optimal structures"?