Final Thoughts

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Higher Temperature Superconductors
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Search for higher Tc’s **

**Challenge: Enormous phase space**

Two approaches:

1. Solid state chemists and physicists trying “crazy” things

2. Guidance from theoretical understanding

Past successes: Nb3Sn, Si under pressure, doped C60, metallic nanotubes,..., CeIn3 (3d) → CeCoIn5 (2d),...  [Marvin Cohen]

** Need high $J_s$, too! - Mac Beasley
Looking under the lamppost

- CUPRATES
- FULLERENES
- PNICTIDES
- ORGANICS
- HEAVY FERMIONS
Looking under the lamppost
Class 1 (el-ph) guidance

Canfield, Cohen, Pickett

• Light atoms, strong el-ph coupling (but no structural transition – caged structures good), high N(E_F), 2d, strong electronic bonds, engineered band structure

• Well understood and promise for higher Tc’s → specific predictions?

• Potential for high Tc’s in hybrid systems?
Cuprate inspired guidance

Tc is optimized for
- optimal doping (crossover between pairing and condensation regimes)
- \(U \sim W\) (near Mott Insulator transition; intermediate coupling \(\xi \sim a\))

\(\rightarrow\) the cuprates are already fairly well optimized. Improve by increasing \(t & U\).

Inhomogeneity – doesn’t hurt or actually helps? Is there an “optimal inhomogeneity”? [Kivelson]
Is there an “optimal frustration”? Get rid of nodes \((s+id)\)?
Composite system with strong pairing \((UD)\) separate but coupled to large carrier density \((OD)\).
How do we identify materials with strong SC pairing but low \(T_c\)?
Fe Pnictide inspired guidance

• Optimal polarizability to reduce on-site Coulomb repulsion
• Fe-As-Fe angle is 70° (need < 90°) → attractive contribution to nn interaction
• Pnictides do a good job of optimizing, but can one design structures using highly polarizable atoms alternating with narrow band metal film for higher Tc’s? [Sawatzsky]

• Cuprates and pnictides lead to ideas of separating carriers and glue, doping and carriers, pairing and phase coherence, optimize doping and bandstructure → use interfaces [JochenMannhart, Peter Abbamonte, Ivan Bozovic]
High Temperature Superconductivity in Cuprates

• [Davis, Yazdani] Universal nodal qp in vanishing ‘arcs’ as doping decreases and incoherent excitations with large pseudogap at antinodal points. Conjectured valence bond glass. Two gaps, but really strongly correlated system with coherent and incoherent spectral weight.
High Temperature Superconductivity in Cuprates

Quantum Oscillations [Suchitra Sebastian] – 3 frequencies in YBCO-6.5, attributed to reconstruction of large Fermi surface due to field induced SDW. Also \( m^* \) strongly increases with reduced doping. Senthil explains this as vortex liquid state and qp scattering off fluctuating \( \Delta \). Large pseudogap at anti-nodal points does not close, but some spectral weight shifted to low energies.
Emergent spatial structure in (mostly) Cuprates

- Static electronic inhomogeneity which break translational and rotational symmetry at the large pseudogap energy scale (Davis, Yazdani). Tendency toward nematic order? (Eun-Ah Kim)
- Evidence of fluctuating stripes in UD regime (John Tranquada)
- Loss of phase coherence at Tc in UD regime supported by STM (qp interference).
- STM also sees static stripy modulations in UD pnictide in AF state oriented along a-axis → large inplane anisotropy in detwinned crystals.

- Cuprates have tendency toward stripes, but are they central to (or help) high Tc and/or to pseudogap?
High Tc Superconductivity in Cuprates

- Eliashberg calculations starting from NFL (Chubukov) and numerical motivation (dynamic cluster MFT – Kotliar, Scalapino) \( \rightarrow \) pairing glue. Eliashberg is used in interpreting various expts, but caution is needed.
- RVB (Anderson) and strange metal (Fisher) have no electron-like qp \( \rightarrow \) no pairing glue. Very difficult, but important, problem.

- What is \( T_c \) of the Hubbard model on a square lattice with \( U \sim 8t \)? What “decorations” would make it higher?
Fe Pnictides

• Pnictides are not the same as the cuprates.

• Pairing mechanism, symmetry and role of correlations still to be sorted out, but evidence points toward renormalized band structure, not to lightly doped Hubbard bands.

• Need to test for s± gap symmetry

• SDW order appears to compete with superconductivity, so that Tc could be increased if one could frustrate this order while maintaining pairing interaction. Unlike cuprates, Drude weight non-vanishing in SDW regime. [Vishwanath]
Other connections

• Doped spin liquids as a route to higher Tc superconductors? Kazushi Kanoda finds superconductivity is not enhanced by proximity to spin liquid behavior.

• Superconductors with topological insulators → Majorana fermions, non-abelian statistics and quantum computing? [ZahidHasan]
The end