Emergent charge order in cuprate superconductors

Bill Atkinson (Trent University)
Sinan Bulut (Augsburg University)
Arno Kampf (Augsburg University)

B. A. K., PRB 88, 155132 (2013)
A. K. B., NJP 17, 013025 (2015)
A. K., PRB 91, 104509 (2015)
A. K. B., PRB 93, 134517 (2016)
Charge Order:

- Has long been observed in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ via STM

Charge order is characterized by

- Incommensurate period of 3–4 unit cells
- Intra-unit cell structure with approximate $d_{x^2-y^2}$ form factor

Is this universal?
Is this a surface effect?
Incommensurate charge order in $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$ (XRD, NMR, ...)

Wu, Nature (2011)
Ghiringhelli, Science (2012)
Comin, Science (2014)
... and many others

Chang, Nat. Phys (2012)

Blanco-Canosa PRB (2014)
Open Questions:

• What is the structure of the CDW? Is it consistent with theory?

![Dy-Bi2212](image)


• What is the mechanism driving the CDW?
  • nearly antiferromagnetic spin fluctuations? [Sachdev, Chubukov, Pépin]
  • short-range Coulomb repulsion? [Atkinson et al.]
  • phonons? [M. Le Tacon, N. Phys 2014]

• How is the CDW related to the pseudogap? To superconductivity?
  • not a direct cause of the PG
  • competes with superconductivity
Multi-orbital approach


$V_{pp}$ can drive a nematic transition
Kim & Fischer, PRB (2011)
Multi-orbital approach

\[
\chi_{\alpha\beta}(q) = \frac{\partial n_\alpha(q)}{\partial \phi_\beta}(q)
\] (gRPA)

To find leading charge instability

\[V_{pp}\] can drive a nematic transition
Kim & Fischer, PRB (2011)

Disagrees with experiments
Multi-orbital approach

What’s missing? Pseudogap

$U_d \approx 10$ eV

Local moments on Cu sites

• Short range dynamical AF correlations

V_{pp} can drive a nematic transition
Kim & Fischer, PRB (2011)


Phenomenological model

• Impose AF order on Cu sites
Effect of Antiferromagnetic order on the charge instability
Atkinson, Bulut, Kampf, NJP 17, 013025 (2015)

Agreement with experiments if charge order emerges from pre-existing pseudogap

Expt. data: Blackburn, PRL (2013)
Disorder and the dCDW

Conventional CDW:

Impurity acts as pinning centre for CDW.
• preserves short-range correlations.
• destroys long-range order.
dCDW is strongly affected by impurities

Zn doping disrupts dCDW form factor ...

\[ \gamma = 1.6909 n_i \]

Suppression mechanism is different than for conventional CDW.
Conclusions:

• Pseudogap is distinct from the dCDW phase; seems to be important for CDW structure

• CDW is strongly suppressed by pointlike impurities; mechanism is very different from conventional CDW.
Structure of Charge Ordered State

Eigenvector of $\chi_{\alpha\beta}(q^*)$ give the orbital contributions to the charge ordered phase.

Predicted pattern has a mix of symmetries