Emergent charge order in cuprate superconductors

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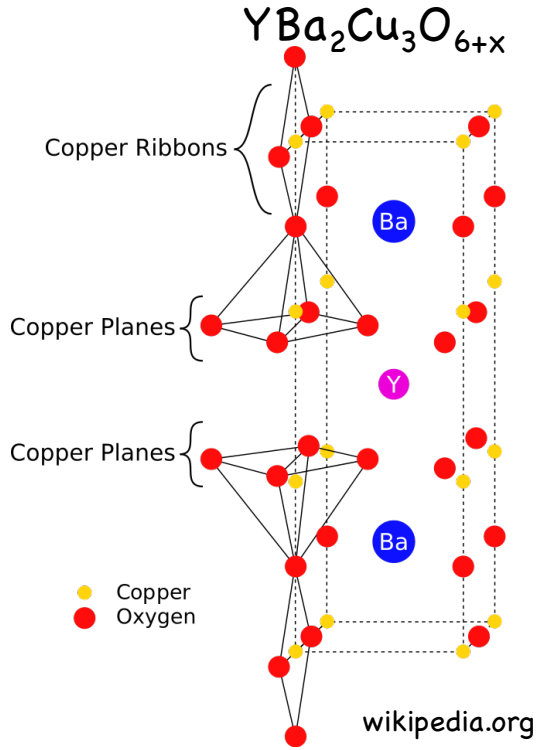
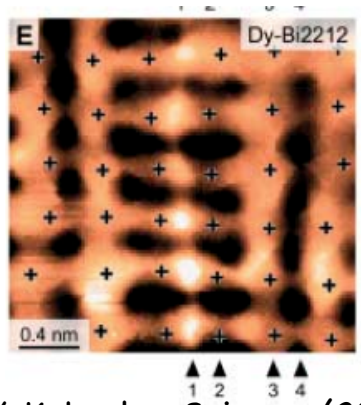


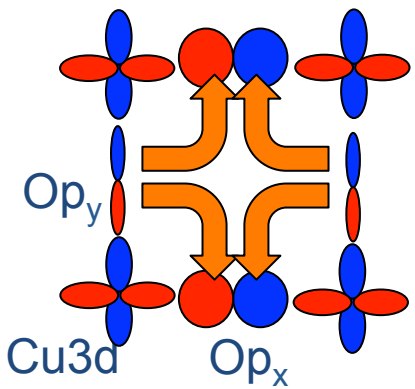
B. A. K., PRB 88, 155132 (2013)
A. K. B., NJP 17, 013025 (2015)
A. K., PRB 91, 104509 (2015)
B. K. A., PRB 92, 195140 (2015)
A. K. B., PRB 93, 134517 (2016)

Charge Order:

- Has long been observed in $Bi_2Sr_2CaCu_2O_8$ via STM



Y. Kohsaka, Science (2007)

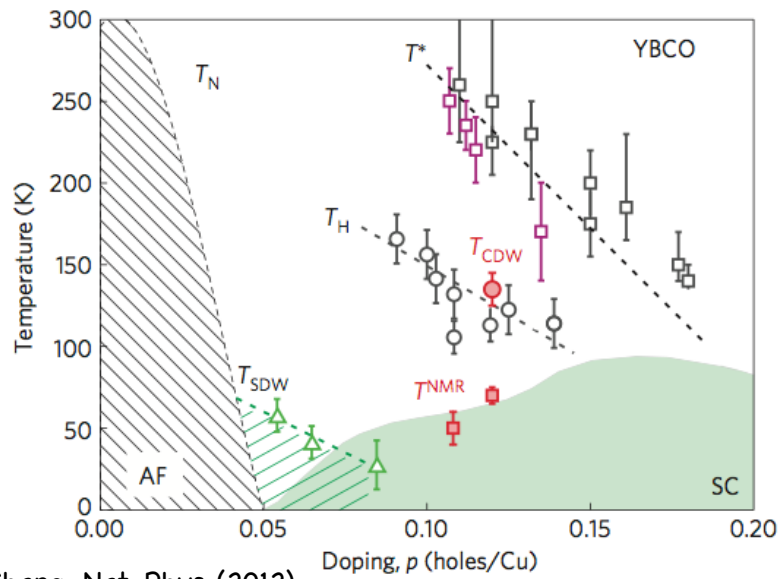


Charge order is characterized by

- Incommensurate period of 3-4 unit cells
- Intra-unit cell structure with approximate d_{x2-y2} form factor

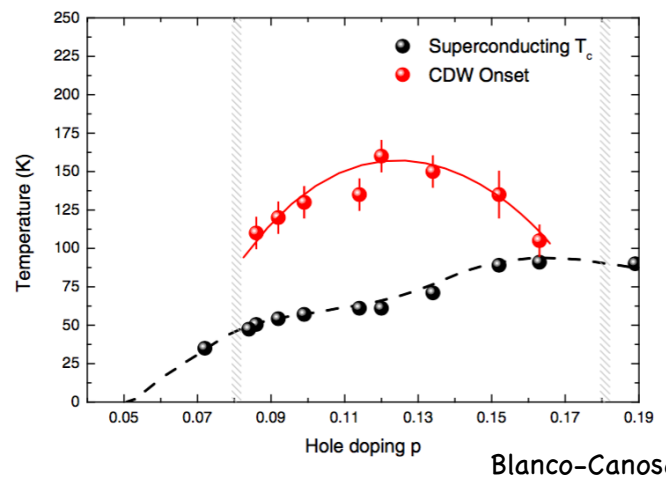
Is this universal?
Is this a surface effect?

Incommensurate charge order in $YBa_2Cu_3O_{6+x}$ (XRD, NMR, …)



Chang, Nat. Phys (2012)

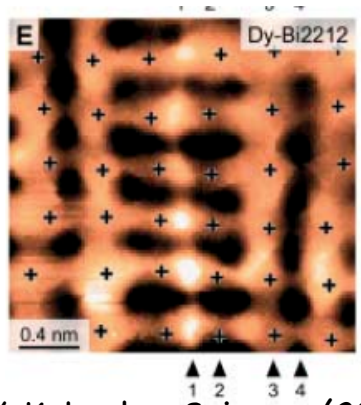
Wu, Nature (2011)
Ghiringhelli, Science (2012)
Chang, Nat. Phys. (2012)
Comin, Science (2014)
… and many others



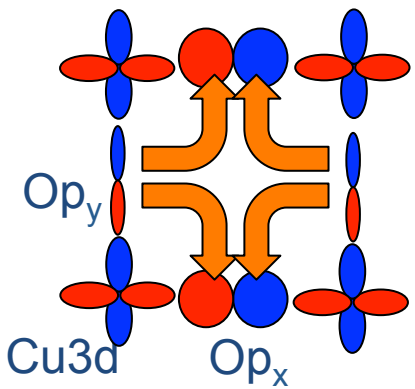
Blanco-Canosa PRB (2014)

Open Questions:

- What is the structure of the CDW? Is it consistent with theory?
  - dCDW-like, but still not fully sorted out. [R. Comin, N. Mat. 2015; E. M. Forgan, N. Comms 2015; N. H. Hamidian, N. Phys 2015]



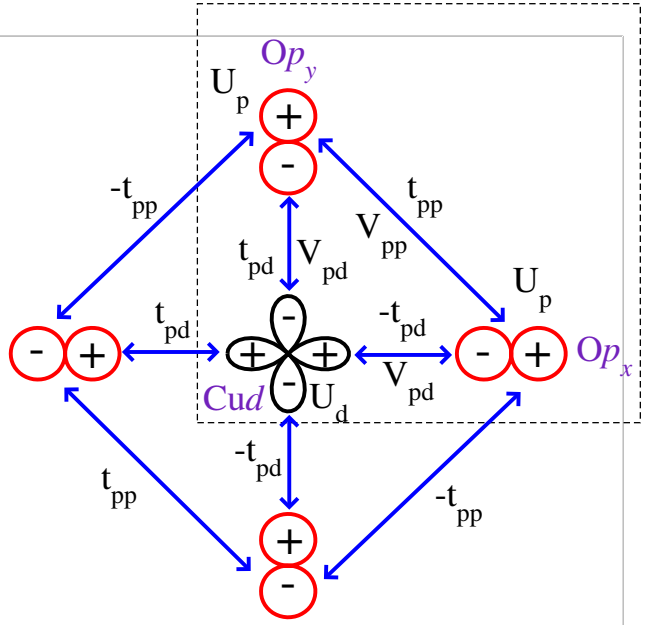
Y. Kohsaka, Science (2007)



- 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

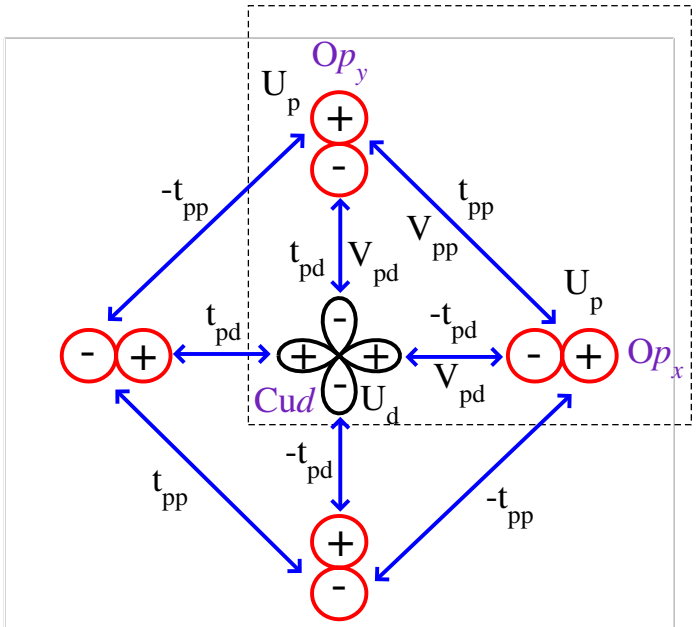
Multi-orbital approach



Phys. Rev. B **88**, 155132 (2013)

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

Multi-orbital approach



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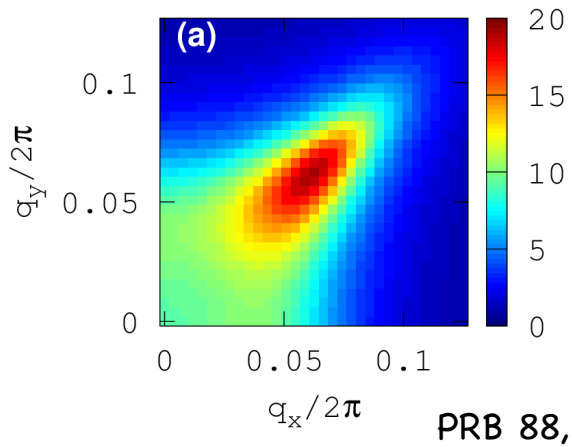
To find leading charge instability

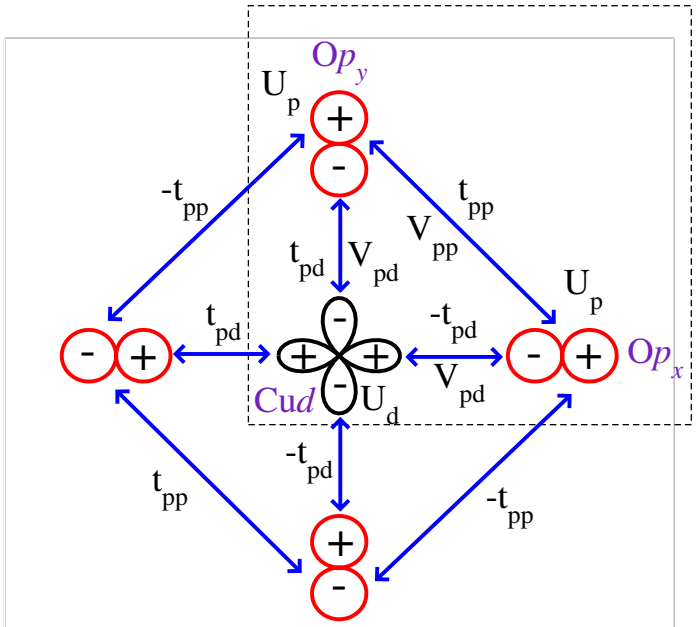
$$\chi_{\alpha\beta}(\mathbf{q}) = \frac{\partial n_\alpha}{\partial \phi_\beta}(\mathbf{q}) \qquad \text{(gRPA)}$$



PRB 88, 155132 (2013)

Disagrees with experiments

Multi-orbital approach



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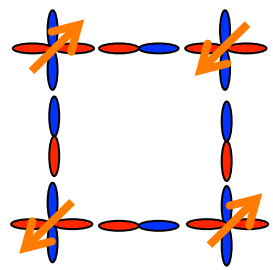
What's missing? Pseudogap

$U_d \approx 10$ eV

Local moments on Cu sites

- Short range dynamical AF correlations



Phenomenological model

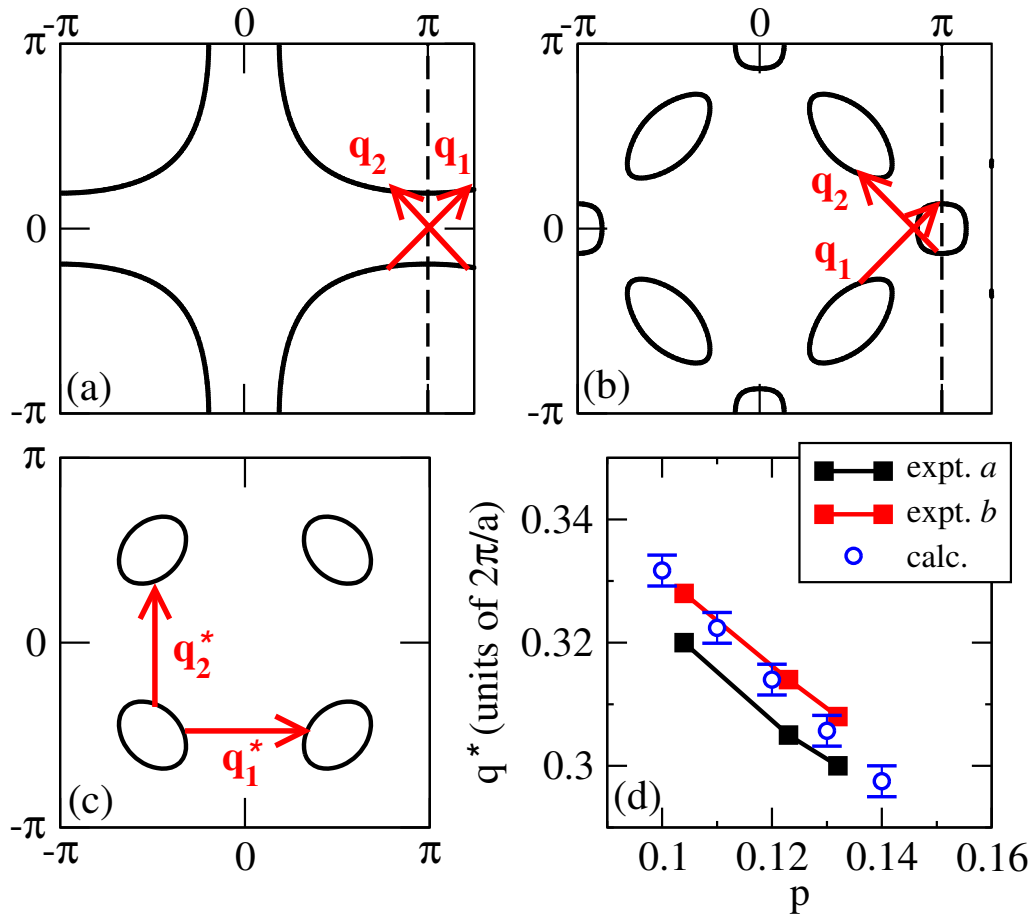
- Impose AF order on Cu sites

Effect of Antiferromagnetic order on the charge instability

Atkinson, Bulut, Kampf, NJP 17, 013025 (2015)

disagree w/ expt

agrees w/ expt

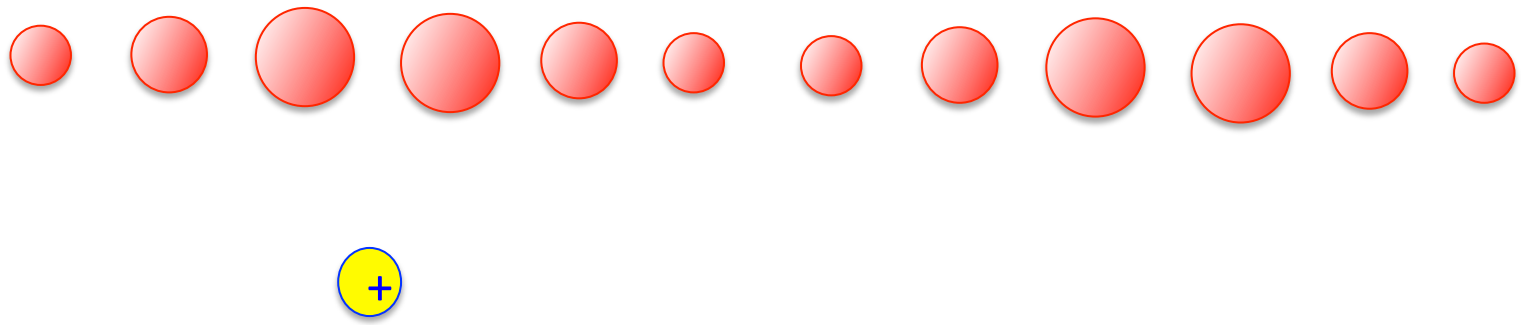


Expt. data:
Blackburn, PRL (2013)

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

Disorder and the dCDW

Conventional CDW:

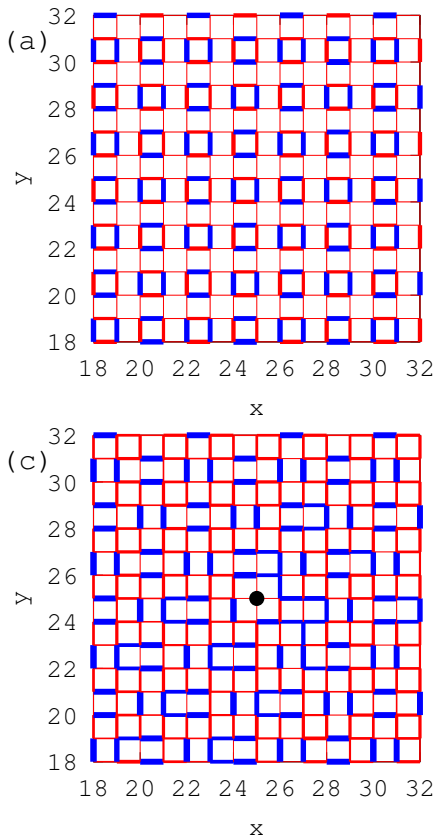


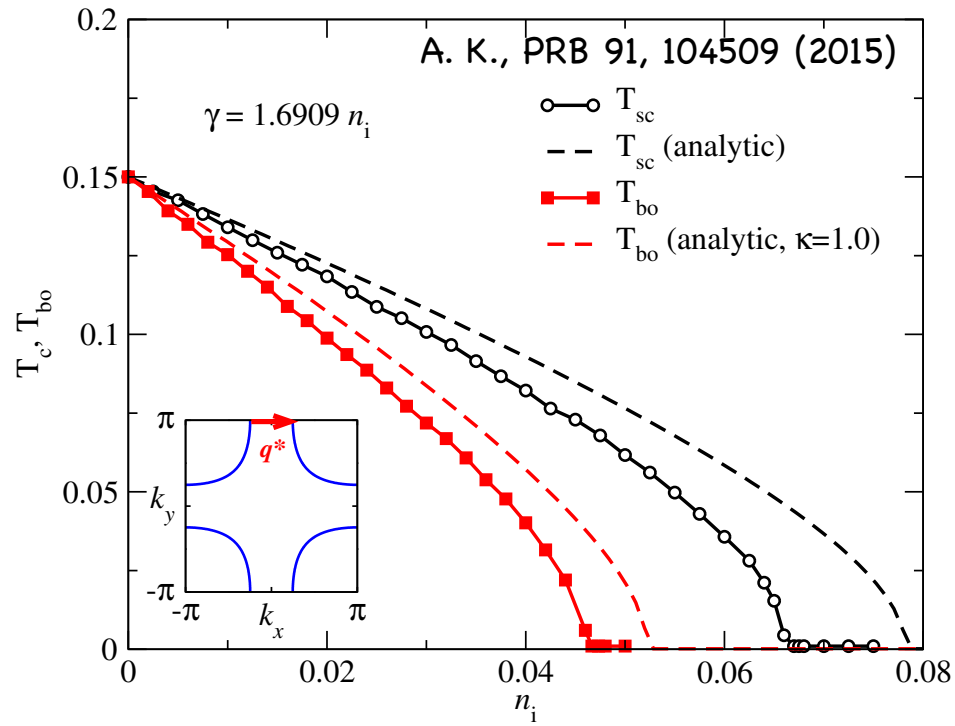
Impurity acts as pinning centre for CDW.

- preserves short-range correlations.
- destroys long-range order.

dCDW is strongly affected by impurities

Zn doping disrupts dCDW form factor ...





... Strongly suppresses dCDW

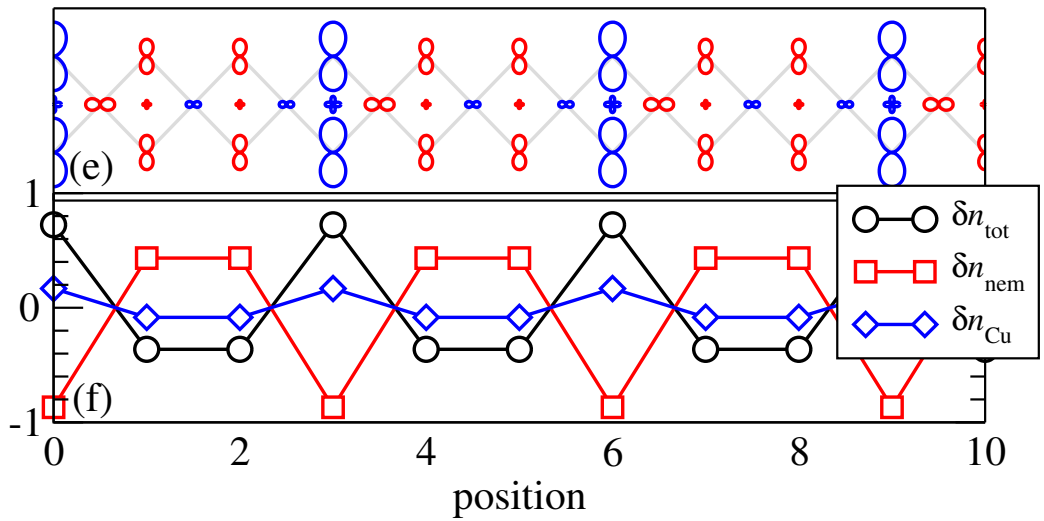
Suppression mechanism is different than for conventional CDW.

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



Predicted pattern has a mix of symmetries