Laboratory for Quantum Matter Research — Prof. Johan Chang

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Between Bands and Bonds

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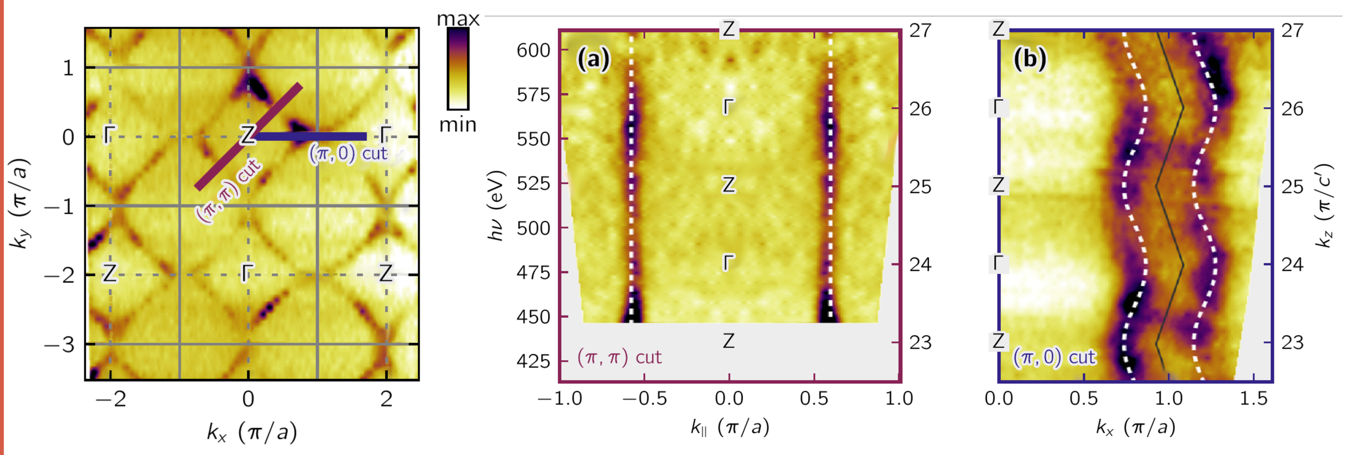
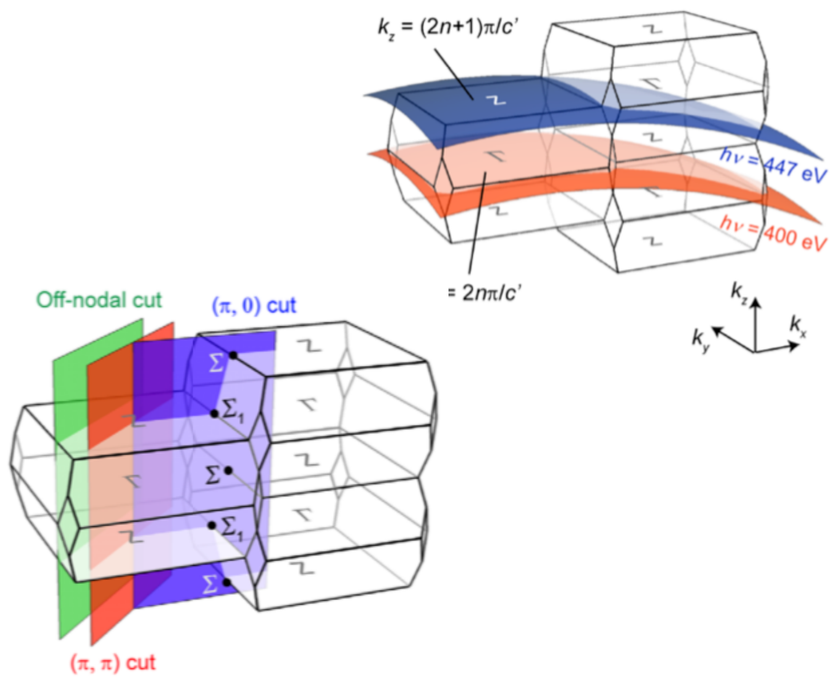
The Laboratory for Quantum Matter Research performs research in current topics in condensed matter physics such as correlated superconductivity, unconventional charge ordering, vortex physics, quantum criticality, and phase competition. We address these topics performing scattering and spectroscopy experiments at large scale neutron and synchrotron facilities as well as in-house laboratory based measurements.

Electronic Band structure

The way electrons (quasiparticles) behave inside a crystal is fundamentally represented by their dispersion relations. Knowledge of the electronic dispersion is therefore crucial to a complete understanding of exotic phenomena such as high-temperature superconductivity.

In-plane and out-of-plane Fermi surface maps by ARPES

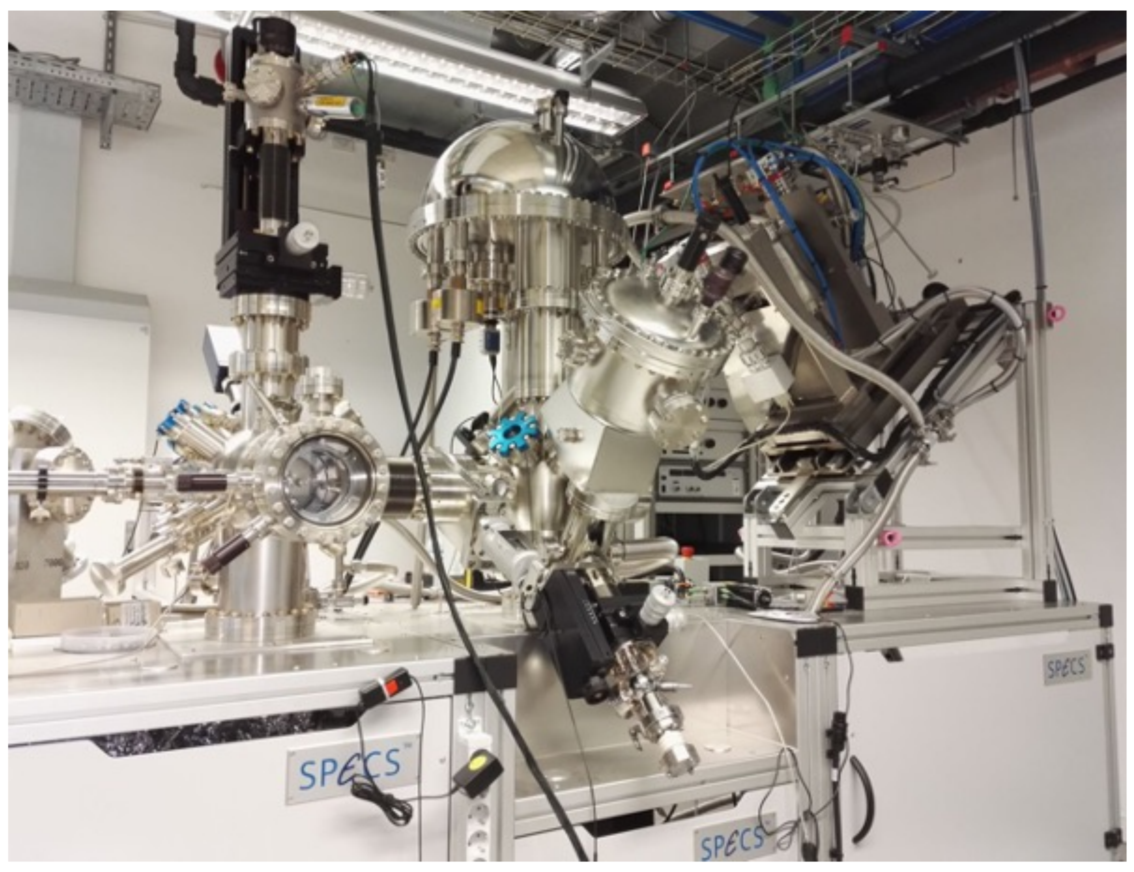




Result: the band structure in $La_{2-x}Sr_xCuO_4$ exhibits a finite dispersion in all three dimensions, as opposed to just two as is the case in related cuprate superconductors [1].

Angle Resolved Photoemission Electron Spectroscopy

ARPES allows us to directly visualize and gain insights into the electronic dispersion by measuring the energy and momentum of electrons ejected from a sample by UV light or x-rays.

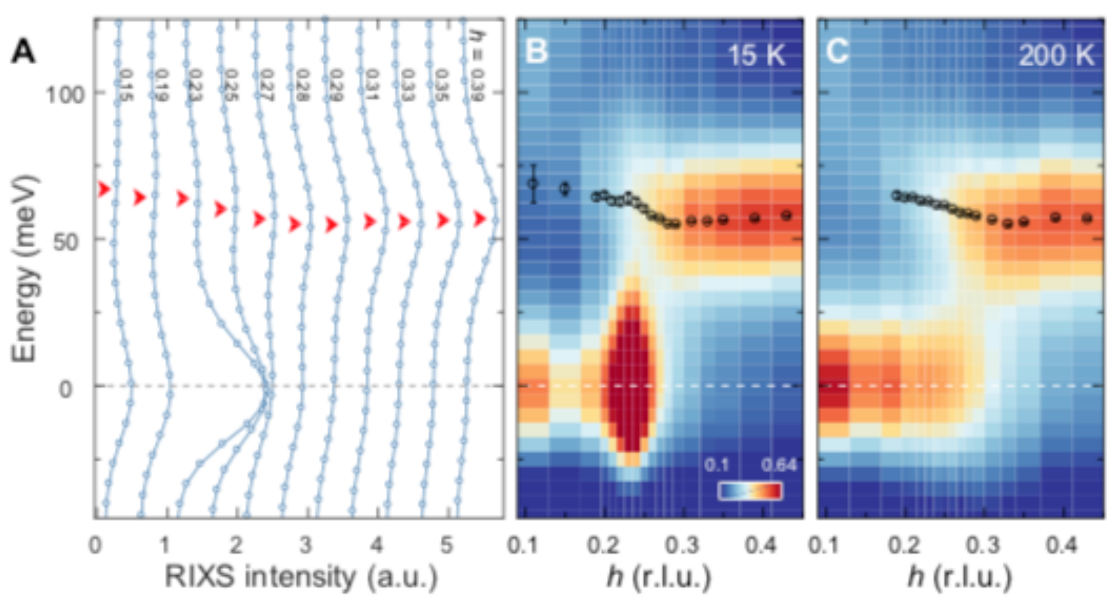


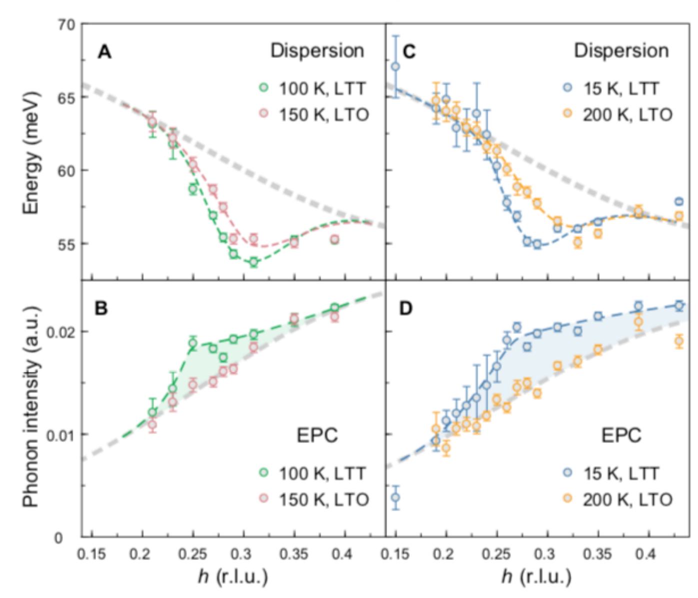
Phonons and Magnons

Charge order is universal to all hole-doped copper-based oxides superconductors, yet the driving interactions for charge order remains an unsolved problem.

Electron-electron or **electron-phonon** interaction?

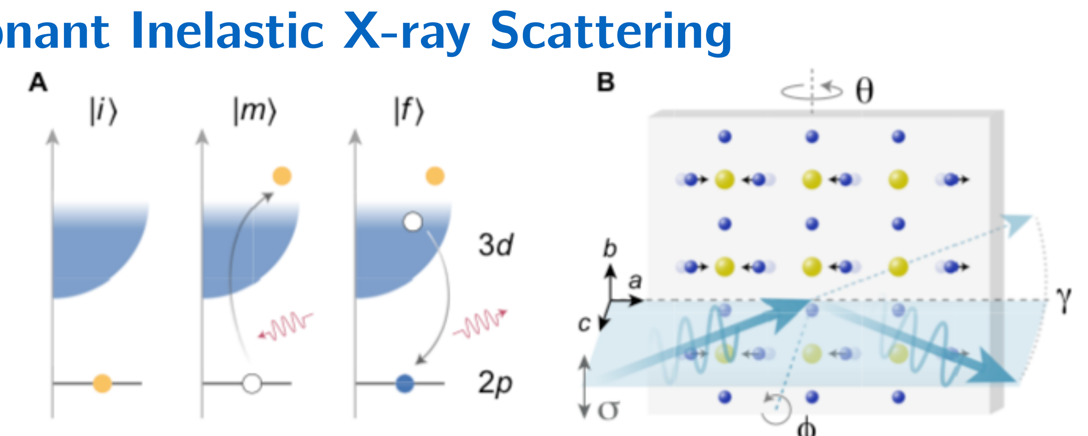
Ultrahigh-resolution RIXS [2]



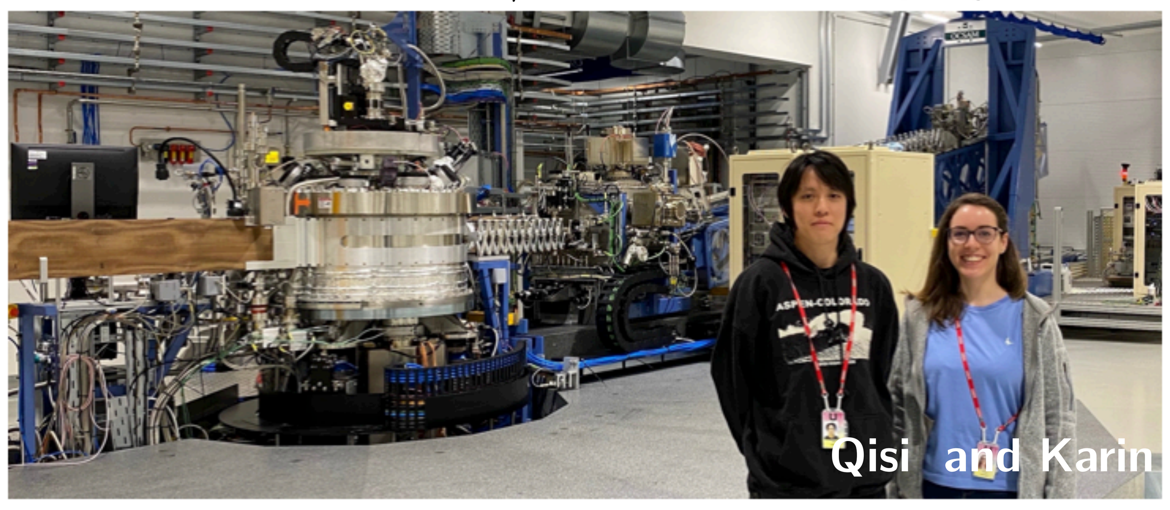


Result: Enhancement of the electron-phonon coupling around the charge-stripe ordering wave vector, thus in addition to electronic correlations, electron-phonon coupling contributes substantially to the emergence of long-range charge-stripe order.

Resonant Inelastic X-ray Scattering



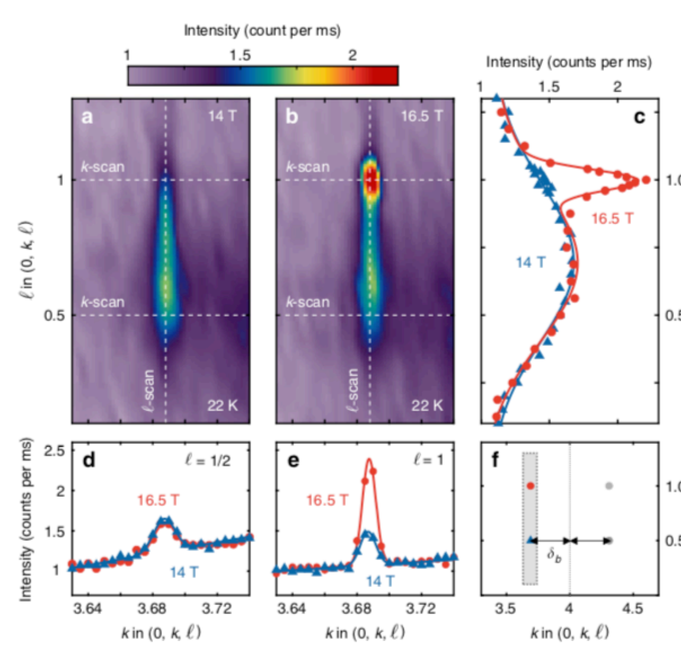
The energy and momentum transfer between the x-ray and sample is measured giving the dispersion relation of the generated excitations. The intermediate resonant state drastically enhances the scattering cross section of related excitation. This allows us to probe weak electronic orders/excitations with very high sensitivity.



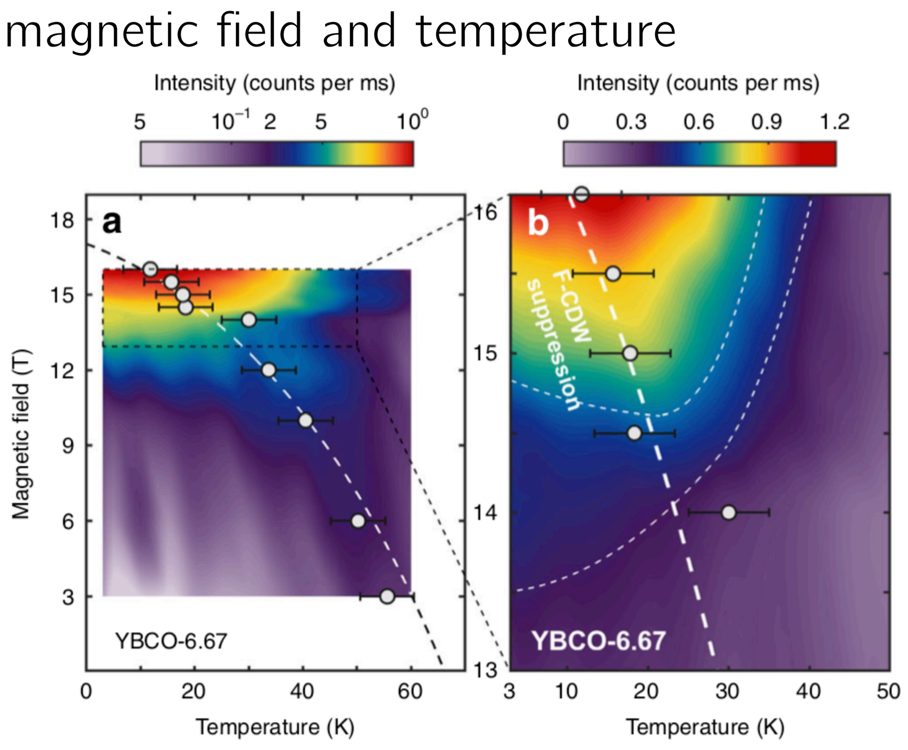
Charge Order

How does superconductivity adjust to ferro- and antiferro- charge order coupling competing orders? Are either of these orders responsible for the electronic reconstruction? [3]

X-ray diffraction of $YBa_2Cu_3O_{6.67}$ as a function of magnetic field and temperature

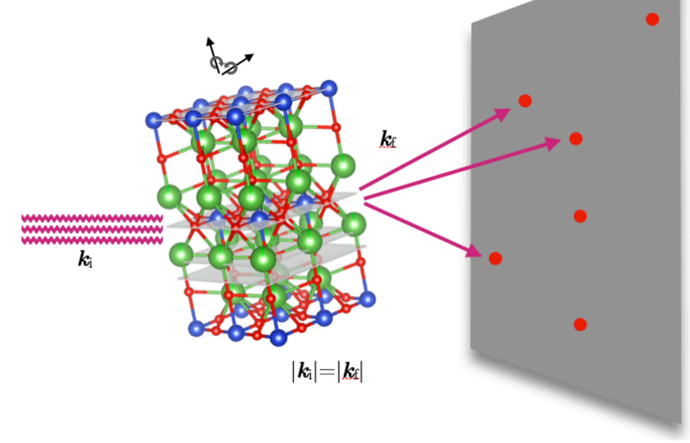


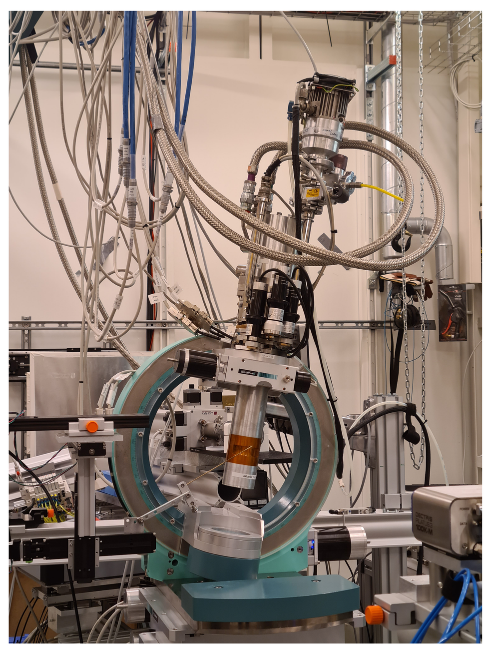
Magnetic-field-induced correlations and three-dimensional charge order



Ferro-charge order correlations suppress superconductivity more strongly than those with anti-ferro correlations. This implies that an inhomogeneous superconducting state exists, in which some regions show a fragile form of superconductivity.

X-ray diffraction





Diffraction provides information on the relative arrangement of the constituents (atoms, nuclei, electrons). That is about the statistic of (long- and short-range order) atomic correlations within the sample.

Such experiments are performed at synchrotron beamlines like P21.1 at DESY in Hamburg (D) or XMaS at ESRF in Grenoble (F).

[1] M. Horio *et al.*, "Three-Dimensional Fermi Surface of Overdoped La-Based Cuprates," *Phys. Rev. Lett.*, vol. 121, no. 7, p. 077004, Aug. 2018, doi: 10.1103/PhysRevLett.121.077004.
[2] Q. Wang *et al.*, "Charge Order Lock-in by Electron-Phonon Coupling in $La_{1.675}Eu_{0.2}Sr_{0.125}CuO_4$" *Science Advances* 7, 27 (2021), doi: 10.1126/sciadv.abg7394
[3] J. Choi *et al.*, "Spatially inhomogeneous competition between superconductivity and the charge density wave in $YBa_2Cu_3O_{6.67}$" *Nature Communications* 11, 990 (2020) doi: 10.1038/s41467-020-14536-1