TWO FLAVORS OF SUPERCONDUCTIVITY IN $YBa_2Cu_3O_{6.67}$

J. Choi*, O. Ivashko*, E. Blackburn, R. Liang, D. A. Bonn, W. N. Hardy, A. T. Holmes, N. B. Christensen, M. Hücker, S. Gerber, O. Gutowski, U. Rütt, M. v. Zimmermann, E. M. Forgan, S. M. Hayden, J. Chang+

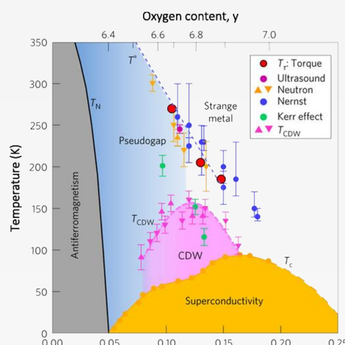
■ YBCO: High-Tc Superconducting Cuprates

+ **Cuprate** (or copper-oxide) is first high-T_c superconducting (HTSC) material family discovered. Two IBM researchers in Zurich, **J. Georg Bednorz** and **K. Alex Müller**, found that $La_{2-x}Ba_xCO_4$ undergoes a transition to superconducting phase at ~40 K. They won the ***Nobel Prize in Physics*** in 1987.

+ **$YBa_2Cu_3O_{7-x}$ (YBCO)** is the first material which becomes a superconductor above **the liquid nitrogen temperature**. It is also one of the most widely studied in both fundamental research and application.

+ **Failure of conventional wisdom**
Microscopic mechanism of superconductivity was well explained by **Bardeen-Cooper-Schrieffer (BCS) theory**: a pair of two electrons mediated by a phonon condenses into the same quantum ground state. However, since **phonons cannot act as a pairing glue at high T**, HTSCs cannot be understood by BCS theory.

+ **What is the mechanism of high-Tc Superconductor?**
125 big scientific questions selected by ***〈Science〉***

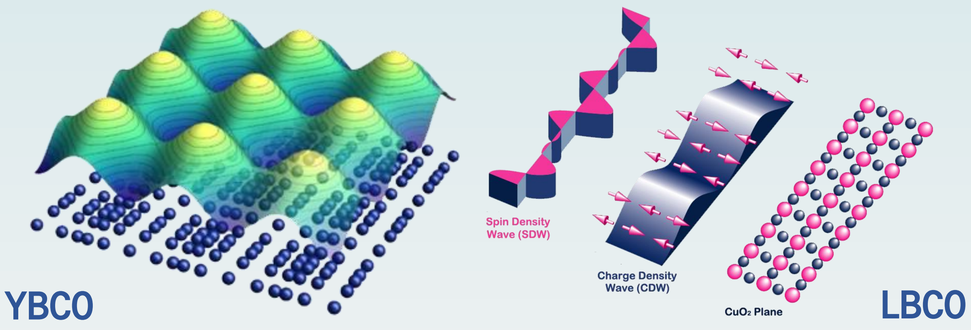


■ New Piece of Puzzle: Density Waves

+ **Charge-Density-Wave (CDW)** is a wave-like periodic modulation of conduction electrons which appears just before the superconductivity emerges. It is now believed that the CDW might be a crucial piece of the cuprate puzzle.

+ **When charge, spin, and orbitals** make density waves, they lead to a modulation of host lattice – **a satellite peak** in an **incommensurate** reciprocal position.

+ **Key Questions:** **What is the relationship between CDW and SC?**



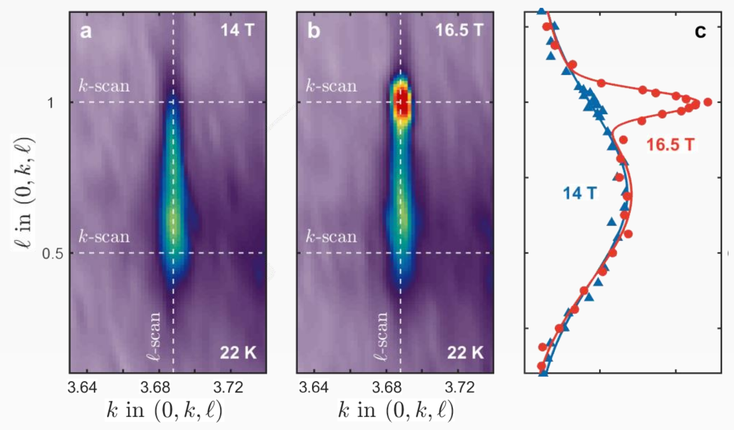
■ Synchrotron X-ray Diffraction

+ **High photon flux of synchrotron** is advantageous to detect an extremely weak satellite CDW peak in YBCO sample – most direct probe for CDW

+ **Extreme environment** of 3 K and 17 T allows to explore an uncharted territory of phase diagram where novel physical phenomena remain undiscovered.

■ What Is New: Spatially inhomogeneous Competition between SC and CDW

Coexistence of Two Different CDW Orders



+ Two spatially-separated CDW coexisting:

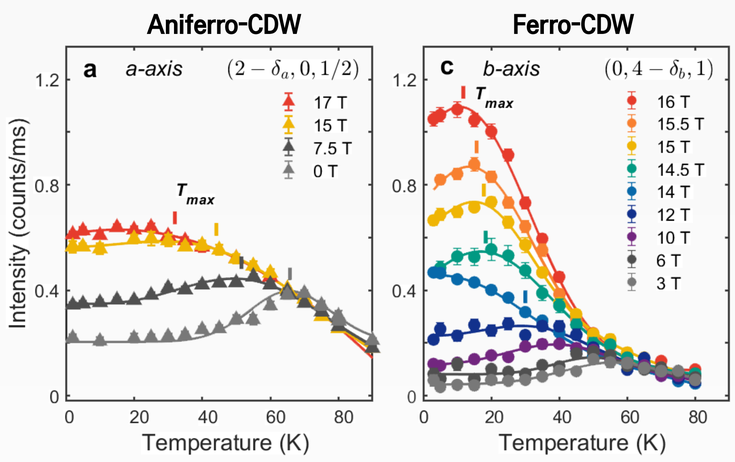
(a) an **antiferro-coupled CDW** stacked in an alternating fashion along c-axis, peaked at /= 0.5 (**AF-CDW**)

(b) A CDW stacked in **ferro-coupled** fashion along c-axis peaked at /= 1 (**F-CDW**)

Competition between SC and CDWs

+ Suppression of CDW peak intensity from Tc indicates CDWs and superconductivity are **competing.**

+ This competition can be characterized by T_{max} **scale.**

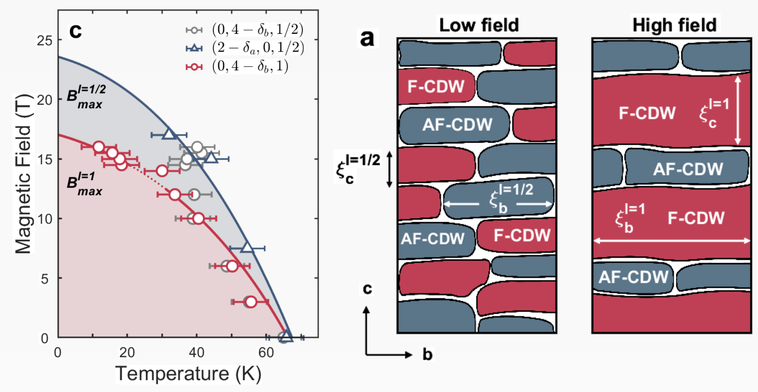


+ 2D intensity mapping reveals:

(a) F-CDW also competes with SC from **low-field range.**

(b) Competition is stronger in **low-T and high-B** region.

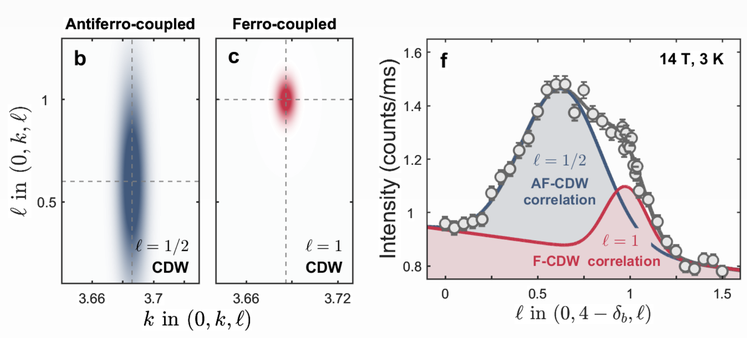
Spatially inhomogeneous Competition



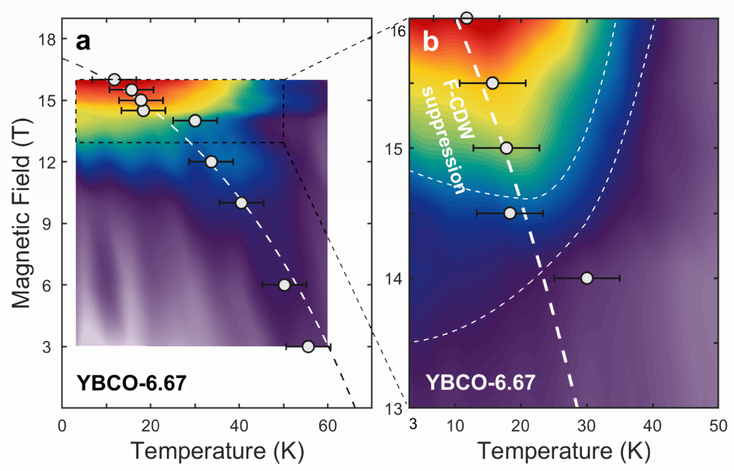
+ T_{max} scales describing the competition are plotted at different magnetic field. T_{max} scales of AF-CDW (blue) and F-CDW (red) evolve in **different way.**

+ The competition between SC and F-CDW is **more severe** than that between SC and AF-CDW – inhomogeneous (spatially) competition

Two-component Analysis



+ To decompose contribution of two CDWs, the intensity is fitted with a sum of two Gaussian function: (a) **AF-CDW contribution** at l = 0.5 and (b) **F-CDW contribution** at l = 1.



CONCLUSION

+ Two different CDW orderings were observed via an x-ray diffraction experiment: **AF-CDW and F-CDW**. Both CDWs coexist, but occupy spatially different regions.

+ Two spatially-separated CDW orders compete with superconducting order differently: **F-CDW competes with SC stronger than AF-CDW does.**

+ We interpret it as two flavors – **strong and weak flavors of superconductivity** in YBCO:

Superconductivity in the region occupied by F-CDW is stronger than the other, thus suppresses F-CDW stronger than SC in the other region suppresses AF-CDW.

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