A cause for 'strange' behavior of cuprates discovered, with superconductor ramifications

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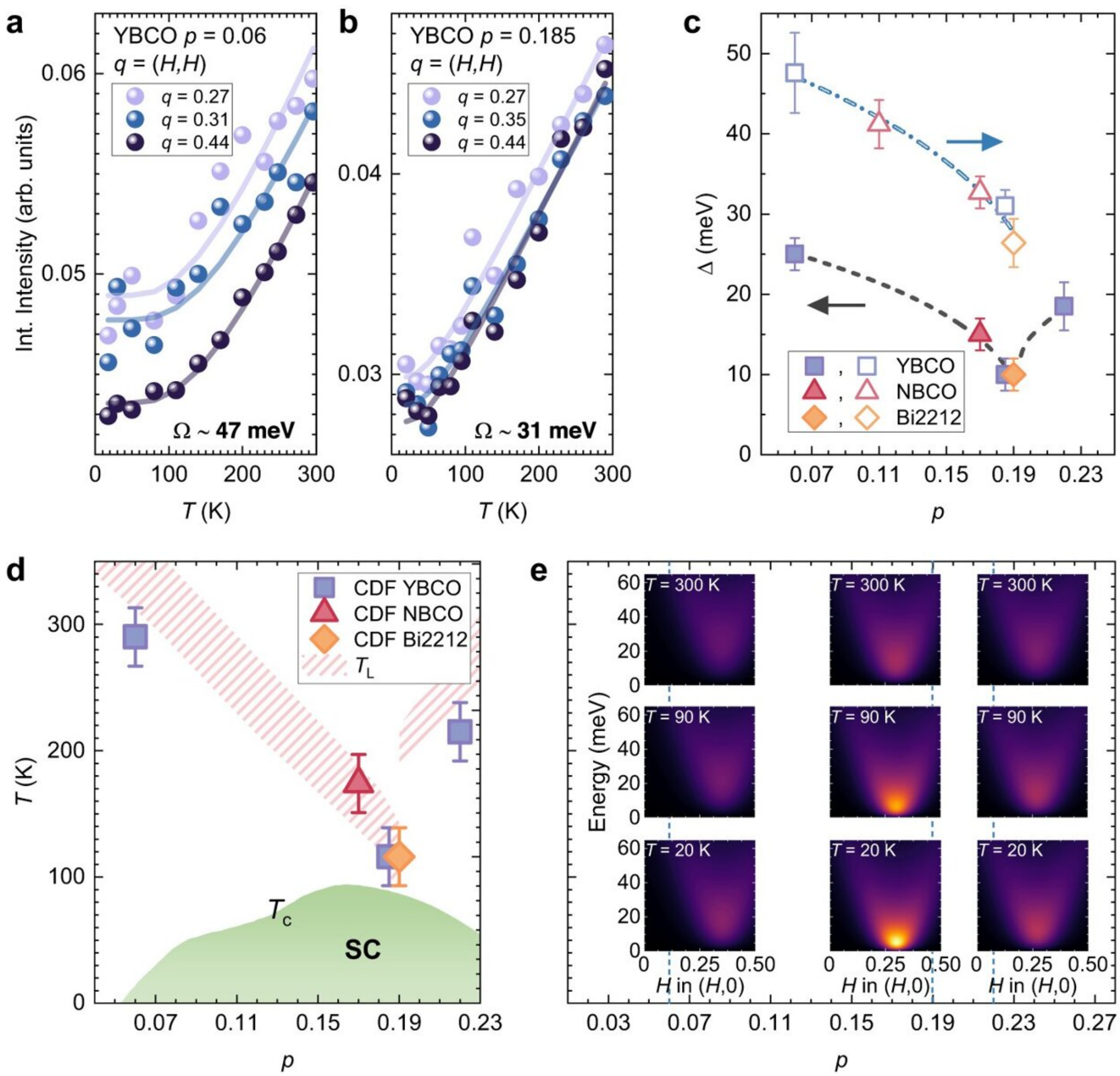

Charge density fluctuations in the cuprate phase diagram. **a** The integrated intensity measured on YBCO ($p \approx 0.06$) is presented as a function of the temperature for several momenta along the (H,H) direction. For each momentum, the solid line represents the fit of the data assuming a Bose distribution function. **b** Same as previous panel, on YBCO ($p \approx 0.19$). **c** The energies Ω, determined from the Bose fit on spectra measured along the (H,H) direction, are plotted together with the energies Δ, directly measured at $q = q_{CDF}$ in the very high resolution spectra. Here and in the next panel we consider the Δ value measured at the lowest temperature. At any doping, $\Omega > \Delta$, as expected when moving away from q_{CDF}. As highlighted by the lines, which are guides to the eye, both energies increase when decreasing the doping, with a minimum at $p = 0.19$. **d** The temperatures corresponding to the energies Δ are presented as a function of doping p as filled symbols. In the constructed cuprate phase diagram, we also show the temperature T_L, where the linear-in-T dependence of the resistance, signature of the strange metal behavior, is lost in YBCO and Bi2212. **e** In the p-T phase diagram, we have depicted the CDF dispersion relation at three temperatures ($T \approx 20$ K, $T \approx 100$ K, $T \approx 300$ K) and doping levels ($p = 0.06$, $p = 0.19$, $p = 0.22$). Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-42961-5

A recent study published in *Nature Communications* by researchers from Politecnico di Milano, Chalmers University of Technology in Göteborg and Sapienza University of Rome sheds light on one of the many mysteries of high-critical-temperature copper-based superconductors. Even at temperatures above the critical temperature, they are special, behaving like "strange" metals. This means that their electrical resistance changes with temperature differently than that of normal metals.

The research hints at the existence of a quantum critical point connected to the phase called "strange metal." A significant step forward in superconductivity research, the discovery could pave the way for sustainable technologies and contribute to a more environmentally friendly future.

"A quantum critical point identifies specific conditions where a material undergoes a sudden change in its properties due solely to quantum effects. Just like ice melts and becomes liquid at 0°C due to microscopic temperature effects, cuprates turn into a 'strange' metal because of quantum charge fluctuations," says Riccardo Arpaia, researcher at the Department of Microtechnology and Nanoscience at Chalmers and leading author of the study.

The research is based on X-ray scattering experiments conducted at the European Synchrotron ESRF and at the British synchrotron DLS. They reveal the existence of charge density fluctuations affecting the electrical resistance of cuprates in such a way as to make them "strange." The systematic measurement of how the energy of these fluctuations varies allowed identifying the value of the charge carrier density at which this energy is minimum: the quantum critical point.

"This is the result of more than five years of work. We used a technique, called RIXS, largely developed by us at the Politecnico di Milano. Thanks to numerous measurement campaigns and to new data analysis methods, we were able to prove the existence of the quantum critical point. A better understanding of cuprates will guide the design of even better materials, with higher critical temperatures, and therefore easier to exploit in tomorrow's technologies," adds Giacomo Ghiringhelli, Professor at the Physics Department of the Politecnico di Milano and coordinator of the research.

Sergio Caprara, together with his colleagues at the Department of Physics of Sapienza University of Rome, came up with the theory that assigns charge fluctuations a key role in cuprates. He says, "This discovery represents an important advancement in understanding not only the anomalous properties of the metallic state of cuprates, but also the still obscure mechanisms underlying high-temperature superconductivity."

More information: Riccardo Arpaia et al, Signature of quantum criticality in cuprates by charge density fluctuations, *Nature Communications* (2023). [DOI: 10.1038/s41467-023-42961-5](https://doi.org/10.1038/s41467-023-42961-5)

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