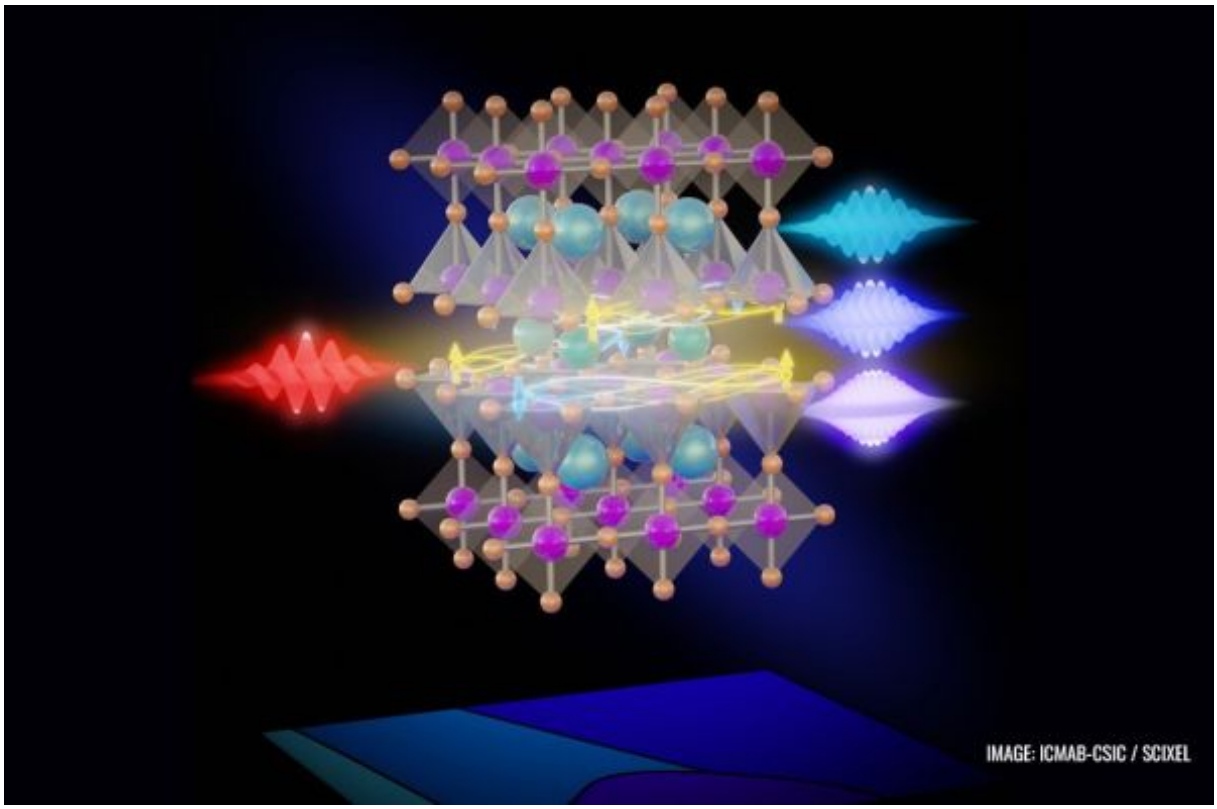


High Harmonic spectroscopy unveils the phase transitions of high-temperature superconductors

Researchers from ICFO, ICMAB-CSIC and Guangdong Technion-Israel Institute of Technology have developed a new methodology to investigate and measure the quantum phase transitions of a high-temperature superconductor by using High Harmonic spectroscopy.

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Superconductors are materials that exhibit the ability to conduct electricity without any resistance. This phenomenon is observed in materials when they are cooled below the so-called superconductor transition temperature, often at very low temperatures (a few degrees above the absolute 0). Among these materials, there are the so-called high-temperature superconductors, which behave as superconductors at temperatures above 77K (the boiling point of liquid nitrogen). These materials are showing to be essential in the development of new electronic and information processing devices as well as optical

quantum computers and even for improving the efficiency of electrical transmission lines. However, high-temperature superconductivity has been seen to be closely linked to the control of their microscopic dynamics. So far, the detection of the different microscopic quantum phases in these complex materials has resulted quite challenging. Not only are the physical processes of these dynamic states still incomplete due to their wide array of quantum states, but the current methods used to explore their dynamics at microscopic scales are lagging sensitivity. Therefore, new tools to better understand the dynamic evolution of these types of superconductors are needed.

Now, in an international study, ICFO researchers Utso Bhattacharya, Ugaitz Elu, Tobias Grass, Piotr T. Grochowski, Themistoklis Sidiropoulos, Tobias Steinle, and Igor Tyulnev, led by ICREA Professors Jens Biegert and Maciej Lewenstein, in collaboration with ICMAB-CSIC researchers Jordi Alcala and Anna Palau, and Marcelo Ciappina, from the Guangdong Technion-Israel Institute of Technology, propose a new methodology based on the use of High Harmonic spectroscopy (HHS) to investigate the transitions between the different phases of YBCO, copper oxide cuprate material which is a well-known high-temperature superconductor. Thi study represents a major scientific breakthrough since it is the first time that highl non-linear and non-perturbative diagnostics/detection methodology is used to understan the behavior of strongly correlated materials

In view of the experimental results obtained, the researchers have also gone beyond an present a new theoretical model to identify the connection between the measured optica spectra and the transition between the different quantum states of the YBCO: strange metal pseudogap, and superconductor. The study has been recently published in the journal PNAS

In their experiment, the researchers used 100nm thick films of YBCO mounted on micro-refrigerator. Firstly, they characterized the superconducting properties of the YBC films and confirmed their quality. Then, by using ultra-short infrared laser pulses the author of the study induced high harmonics generation in the material samples, which were place inside a vacuum chamber and cooled to a temperature of 77K

High Harmonics are the high-energy photons emitted by the electrons of a system when it i placed in a strong laser field. These emitted photons have a frequency many times that of th driving laser field

When they hit the surface, they recorded the reflected radiation with a spectrograph to stud the harmonic spectrum, which contains the imprints of this nonlinear optical response, an was found to have a connection with the phase transitions

Seeing these experimental results in the lab and the lack of a theory that could explain wha was being observed, the researchers developed a new strong-field quasi-Hubbard model t shed light on the connections between the measured high harmonics and the formation o Cooper pairs, that is, the paired electrons that are responsible for the superconductin phase

When using this new theoretical model, the theoretical calculations of the high harmoni

spectra obtained matched the experimental data. "The model faithfully reproduces th functional form of the measurement data over the entire temperature range and for severa orders of magnitude of harmonic amplitude", the authors highlighted. This new approach, a they noted, has permitted a theoretical connection between the measurements and th underlying microscope dynamics providing a "powerful new methodology to study th quantum phase transitions" in correlated materials

Finally, the team highlights that their work provides a "first striking example" of how Hig Harmonic Spectroscopy can be used to distinguish correlated phases of matter. They als consider that it paves the way toward a "refined understanding of the physical processes tha occur inside high-temperature superconductorsi¿

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