ICFO

Image not found

Making spatial images of quantum interactions in twisted materials through an innovative nano-optical microscopy tool

Twisted two-dimensional (2D) materials host a wide range of correlated quantum phenomena, including superconductivity and exotic ferromagnetism. Their fundamental and technological relevance has driven the search for techniques capable of capturing the intricate electron interactions leading to these behaviors.
In a recent Nature Physics article, ICFO researchers have now presented photothermoelectric nanoscopy as an innovative tool for identifying strong electron correlations in twisted 2D materials with nanometer-level spatial precision, revealing key details that traditional methods had previously missed.

January 02, 2026

In quantum physics, when a large number of electrons are brought together under carefully tailored external conditions, they start to behave collectively, showing strong correlations that can give rise to superconductivity, correlated insulators, or exotic forms of ferromagnetism, among others. This naturally occurs in twisted two-dimensional materials -one-atom-thick layers stacked with a slight rotation between them-, which have consequently become convenient platforms to study these correlated behaviors.

In the quest for uncovering the most intricate and fundamental details of correlated quantum phenomena, ICFO researchers **Dr. Sergi Batlle Porro**, **Dr. Roshan Krishna Kumar**, **Dr. Niels C. H. Hesp**, **Dr. Petr Stepanov**, led by **ICREA Prof. Frank Koppens**, have recently presented a novel tool in Nature Physics called **photothermoelectric nanoscopy**. Showcased with **twisted symmetric trilayer graphene** (three graphene layers, with a 1.5º twist between the middle on and the others), the technique**identified strong electron correlations** that cannot be accounted for by conventional semiconductor models. This study was conducted together with Princeton University, University of Oxford, Donostia International Physics Center, National Institute for Materials Science (Tsukuba, Japan), IKERBASQUE, and University of Notre Dame.

Photothermoelectric nanoscopy works by focusing infrared light onto a minuscule nanoscale hot spot on the sample. Due to the so-called Seebeck effect, this temperature rise generates a voltage, which can then be mapped with nanometer precision. ï¿½We recorded a high y unusual thermoelectric response, a clear indicator of correlated physics,ï¿½ explains Dr. Sergi Batlle Porro, first author of the article. Ultimately, they obtained **exceptionally detailed depiction of how strong correlations emerge and evolve in twisted 2D materials**, including how different twist angles and interaction strengths affect its behavior, thereby **uncovering key information that was unattainable with previous methods**.
The experimental results were especially consistent with the **heavy-fermion model**. According to this framework, some electrons in twisted trilayer graphene behave as if they had a much larger mass, which prevents them from freely moving and contributing to the electrical current, while others are mobile and conduct current. ï¿½This disparity is not se n in typical semiconductors,ï¿½ shares Dr. Batlle. ï¿½In fact, it facilitates strong interac ions, which can lead to exotic quantum phenomena.ï¿½ The collaborative theory t am from Princeton had predicted that these phenomena can be probed through the Seebeck effect, which turned out to be an accurate pre
iction. The team also found that the correlated behavior appears over a wide range of angles, between roughly 1.30° and 1.55°, offering a much broader window compare to other commonly used platforms such as twisted bilayer graphene. ï¿½With these **less stringent engineering conditions**, trilayer graphene emerges as an attractive, adjustable platform for studying correlated phases,ï¿½ claims ICREA Prof. Frank Koppens, lead researcher of t e stud
. Now, the researchers would like to adapt photothermoelectric nanoscopy for use t temperatures below one Kelvin (better suited for detecting exotic quantum phenomena) a d to apply it to other twisted 2D materials, which might host similar heavy-fermion-li e behavior

Reference:

Batlle Porro, S., C?lug?ru, D., Hu, H. et al. Photovoltage microscopy of symmetrically twisted trilayer graphene. Nat. Phys. (2025).
DOI: https://doi.org/10.1038/s41567-025-03071-9

Acknowledgements:
F.H.L.K. acknowledges support from the ERC TOPONANOP (726001), the Government of Spain (PID2019-106875GB-I00, PID2022-141081NB-I00, Severo Ochoa CEX2019-000910-S and CEX2024-001490-S, PCI2021-122020-2A funded by MCIN/AEI/ 10.13039/501100011033), the European Union NextGenerationEU/PRTR (PRTR-C17.I1) within the FLAG-ERA grant

[PhotoTBG], by ICFO, RWTH Aachen and ETHZ/Department of Physics, Fundacio Cellex, Fundacio Mir-Puig and Generalitat de Catalunya (CERCA, AGAUR, 2021 SGR 01443). Furthermore, the research leading to these results received funding from the European Union's Horizon 2020 programme under grant agreement no. 881603 (Graphene flagship Core3) and 820378 (Quantum flagship). This material is based upon work supported by the Air Force Office of Scientific Research under award no. FA8655-23-1-7047. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Air Force. D.C. acknowledges the hospitality of the Donostia International Physics Center, at which this work was carried out. B.A.B. was supported by DOE grant no. DE-SC0016239. D.C. was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 101020833), the Simons Investigator programme (grant no. 404513), the Gordon and Betty Moore Foundation (grant no. GBMF8685 towards the Princeton theory programme), the Gordon and Betty Moore Foundation's EPiQS Initiative (grant no. GBMF11070), the Office of Naval Research (ONR grant no. N00014-20-1-2303), the Global Collaborative Network Grant at Princeton University, BSF Israel US foundation grant no. 2018226 and NSF-MERSEC (grant no. MERSEC DMR 2011750). H.H. was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 101020833) and the Schmidt Fund Grant. P.S. acknowledges support from the European Union's Horizon 2020 research and innovation programme under the Marie Sk?odowska-Curie grant no. 754510. S.B.P. acknowledges funding from the ?Presidencia de la Agencia Estatal deInvestigacion' within the PRE2020-094404 predoctoral fellowship. N.C.H.H. acknowledges funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sk?odowska-Curie grant agreement ref. 665884. K.W. and T.T. acknowledge support from JSPS KAKENHI (grant refs. 19H05790, 20H00354 and 21H05233).