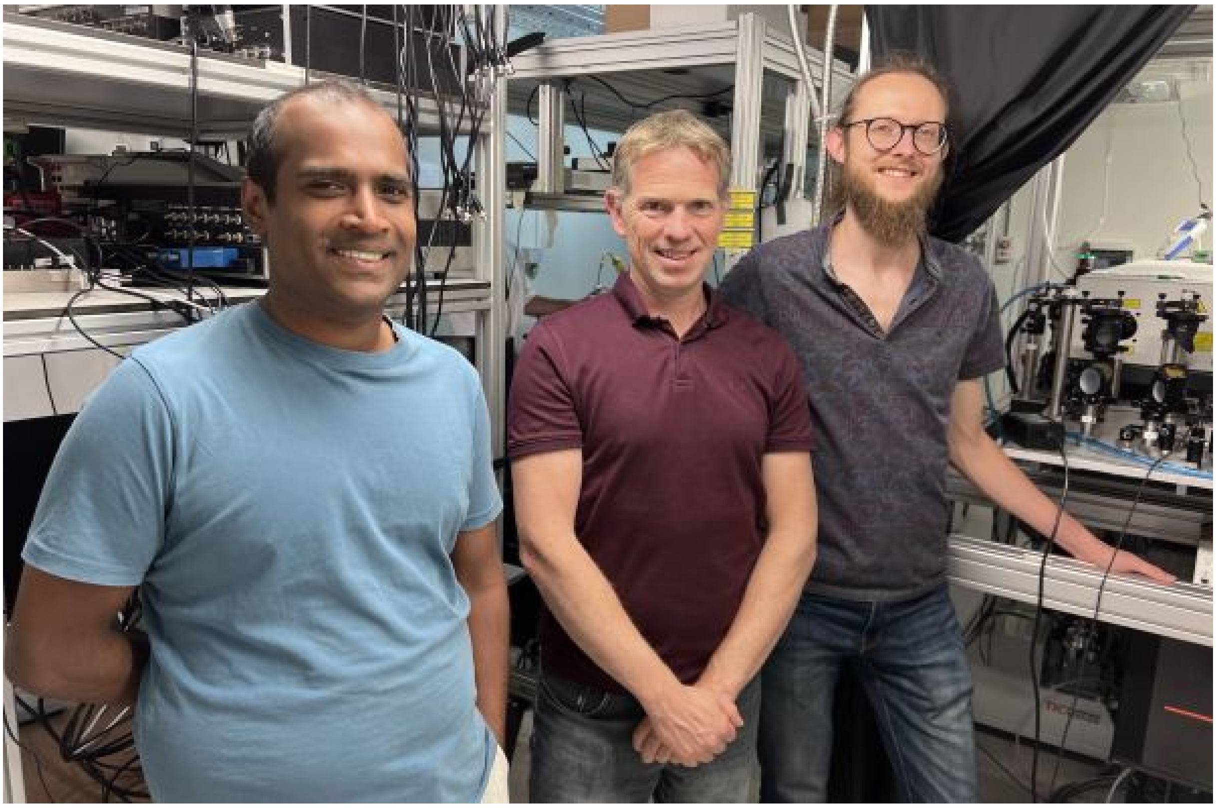

ICFO researchers overcome long-standing bottleneck in single photon detection with twisted 2D materials

While studying layered two-dimensional materials, ICFO researchers observed an anomaly-an unexpected transition in the system's state triggered by light. That anomaly turned out to be single-photon sensitivity with extraordinary properties which were previously inaccessible: the ability to detect long-wavelength photons (up to the mid-infrared) at relatively high temperatures. The results of this study, published in Science, open the door to a wide range of applications, from bioimaging to observational astronomy and quantum technologies.

August 07, 2025

The ability to detect single photons (the smallest energy packets constituting electromagnetic radiation) in the infrared range has become a pressing need across numerous fields, from medical imaging and astrophysics to emerging quantum technologies. In observational astronomy, for example, the light from distant celestial objects can be extremely faint and require exceptional sensitivity in the mid-infrared. Similarly, in free-space quantum communication-where single photons need to travel across vast distances-operating in the mid-infrared can provide key advantages in signal clarity.

The widespread use of single photon detectors in this range is limited by the need for large, costly, and energy-intensive cryogenic systems to keep the temperature below 1 Kelvin. This also hinders the integration of the resulting detectors into modern photonic circuits, the backbone of today's information technologies.

An international team of researchers led by ICFO has now shown one way to overcome this limitation. They have used two-dimensional materials (which are only one-atom thick) to detect long-wavelength single photons (up to the mid-infrared) at relatively high temperatures (around 25 degrees Kelvin). This milestone has caught the attention of the European Space Agency (ESA), which is seeking the use of detectors with these type of properties for space exploration.

Today, ICFO researchers, **Dr. Krystian Nowakowski**, **Dr. Hitesh Agarwal**, **Dr. Julien Barrier**, **Dr. David Barcons Ruiz**, **Dr. Geng Li**, **Riccardo Bertini**, **Matteo Ceccanti**, **Dr. Iacopo Torre**, **Dr. Antoine Reserbat-Plantey**, led by **Dr. Roshan Krishna Kumar** and **ICREA Prof. at ICFO Frank Koppens**, in collaboration with **Prof. Pablo Jarillo-Herrero**, researcher and professor at Massachusetts Institute of Technology (MIT) and Distinguished Invited Professor at ICFO, as well as researchers from the University of Manchester, University of Antwerp, among others, have reported their results in Science.

Bistability: a novel mechanism for single photon detection

i¿½In our group, we combine different 2D materials. We stack them, twist them, and th
n observe what happens. And, sometimes, surprises come out,i¿½ comments ICREA Prof
at ICFO Frank Koppens, senior author of the study and long-time expert in 2D materi
ls. A slight twist between layers induces an interference pattern known as the moire patt
rn, which modifies the properties of the electrons in the material. Several exotic propert
es, including superconductivity or orbital magnetism, have been observed in moire lattices
In this work, **ICFO together with the international team have added another exotic property to the list,** a phenomenon known as **bistability.** Bistability allows a system to rest in two distinct states under the same external conditions, like a light switch that can remain stable in either the i¿½oni¿½ or i¿½offi¿½ po
itions. The team has shown that bistability can serve as a new mechanism for singl
-photon detection-one of those surprises Koppens describes. i¿½We noticed that the materi
l was not behaving as we expected,i¿½ he recalls. i¿½So, we thought, ?Let's shine some l
ght on it and see what happens.' That's when we suddenly observed an extreme
ensitivity to illumination.i¿½ And the deeper they looked, the clearer it became that

he material was responding to ind

Single photons: the straw that broke the camel's back

The detector itself is structurally simple. It consists of bilayer graphene (a one-atom-thick layer of carbon atoms, which shows relevant physical properties) sandwiched between layers of hexagonal boron nitride (hBN), another 2D material which acts as a protective shield. However, ï¿½building the device was tricky,ï¿½ explains Dr. Hitesh Agarwal, first co-autho
of the study, primarily because achieving the precise alignment between bilayer graphene and hBN had only a 50% success rate. ï¿½In the end, we managed to solve it through c
reful design and lessons from earlier experiments,ï¿½
e adds. So how does this device detect single photons? At an intuitive level, the answe
can be grasped with a metaphor. Imagine a huge, empty box on a table, and put a handful o
straws (or grains of rice) inside. Nothing happens. But what if you keep putting in more
nd more straws or rice? Eventually, the weight will become too much, and the table will c
llapse. In the laboratory, the researchers engineered a system at the edge of collapse. ï¿½
nstead of straws, we have electrical current that is flowingï¿½, says Dr. Krystian Nowak
wski, first co-author of the paper. ï¿½And when we reach the critical point, the device doe
n't break but suddenly switches from one stable state to another. When a single photon is
bsorbed, it's like that final straw-it triggers the transition, and that's what
we detect.ï¿½ But how exactly does a lone, single photon tip the system? ï¿½This is some
hing we would all love to know,ï¿½ admits Dr. Nowakowski. ï¿½We have some hypothe
es at the moment, but we need to do more experiments to be able to discern between them.ï
?½ For now, we'll have t
live with the mystery. What is clear, however, is that this mechanism differs fundame
tally from conventional superconducting or semiconductor-based processes. It was p
ecisely this underlying mechanism that allowed **the device to detect long wavelength photons (up to the mid-infrared) at relatively high temperatures (around 25 degrees Kelvin)**. ï¿½The uniq
e physical mechanism at the heart of our detector architecture allows us to break t
e fundamental limits that held previous technologies back,ï¿½ shares Dr. Krishna Kumar, who co-supervised the w
rk. As for the results obtained in the experiment, Prof. Jarillo-Herrero highlights, ï¿
?This experiment showcases the great potential of moire quantum devices not only in te
ms of fundamental science but also for novel applications in quantum technologi
siï¿½. The team is now focused on making the system more compact and pushing the o
erating temperature even higher, since this is usually the deciding factor that determines w
ether a certain detector will be used at all. However, many more factors come into p
ay when determining whether a given technology will become practical. Perhaps this new me
hod for detecting single photons won't prove useful for studying distant galaxies, medically
elevant molecules, or quantum information carriers -or perhaps it will become a turnin

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Acknowledgements:
PJH acknowledges support by AFOSR grant FA9550-21-1-0319, the Gordon and Betty Moore Foundation's EPiQS Initiative through Grant GBMF9463, the Ramon Areces Foundation, and the ICFO Distinguished Visiting Professor program. F.H.L.K. acknowledges support from the ERC TOPONANOP (726001), the government of Spain (PID2019-106875GB-I00; Severo Ochoa CEX2019-000910-S [MCIN/ AEI/10.13039/501100011033], PCI2021-122020-2A funded by MCIN/AEI/ 10.13039/501100011033), the "European Union NextGenerationEU/PRTR (PRTR-C17.I1), Fundacio Cellex, Fundacio Mir-Puig, and Generalitat de Catalunya (CERCA, AGAUR, 2021 SGR 01443). Furthermore, the research leading to these results has received funding from the European Union's Horizon 2020 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 number 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. J.B. acknowledges support from the European Union's Horizon Europe program under grant agreement 101105218. R.S., B.J., M.V.M. and L.C. acknowledge support from Research Foundation-Flanders (FWO) research projects G0A5921N and 11E5821N. H.A., K.N. and R.B. acknowledge funding from the European Union's Horizon 2020 research and innovation programme under Marie Sk?odowska-Curie grant agreement no. 665884, 713729 and 847517, respectively. V.F. and S.S acknowledge support from EPSRC Grants EP/S019367/1, EP/P026850/1, and EP/N010345/1; British Council project 1185409051. D.B.R. acknowledges funding from the Secretaria d'Universitats i Recerca del Departament d'Empresa i Coneixement de la Generalitat de Catalunya, as well as the European Social Fund (L'FSE inverteix en el teu futur)-FEDER. R. K. K acknowledges funding by MCIN/AEI/ 10.13039/501100011033 and by the ï¿½European Union NextGenerationEU/PRT " PCI2021-122020-2A within the FLAG-ERA grant [PhotoTBG], by ICFO, RWTH Aachen a d ETHZ/Department of Physics, and support from the Ramon y Cajal Grant RYC2022-036118 I funded by MICIU/AEI/10.13039/501100011033 and by ï¿½ESF+ï¿½. R.B. ackn wledges funding from the European Union's Horizon H2020 under the Marie Sklodowska-Cur e grant agreements No 847517.