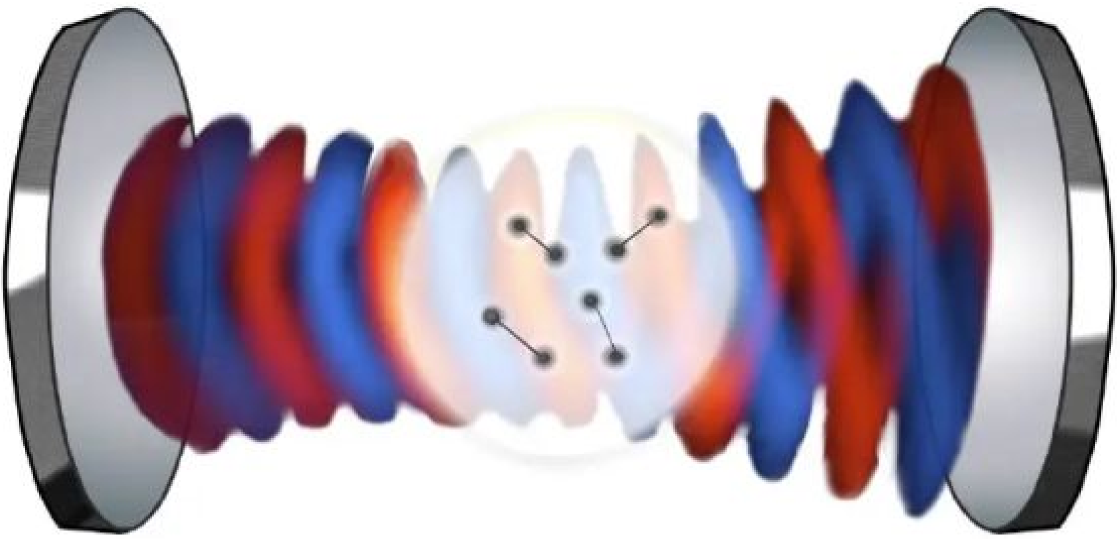

Playing with light and molecules: a versatile platform for exploring exotic quantum matter

In a Physical Review Letters publication, ICFO researchers have theoretically proposed a new method that uses molecules and light to study exotic states of matter in which several quantum effects, such as non-local interactions and geometric frustration, can emerge. The platform is more versatile and robust than existing alternatives.

March 17, 2026

Quantum effects can be elusive, intricate, and deeply complex. That's why, sometimes, researchers need to specifically design platforms that imitate these quantum phenomena in a ï¿½cleanï¿½ and highly controllable manner, minimizing the disturbances often foun

in nature. Sometimes, as it turns out, these synthetic quantum matter systems are their

nly means to grasp such effe

ts. Traditionally, researchers have used ultracold atoms to engineer complex qua tum interactions, including non-local couplings -interactions that span the entire system, allo ing distant atoms to influence each other. Non-local couplings lie at the core of fundame tal quantum properties like entanglement, and can give rise to phenomena of interest, suc as geometrical frustration, in which these interactions prevent the system from settling in o a unique configuration that minimizes its energy, potentially leading to exotic phase of mat

er. These platforms, while effective, often require rapid, repetitive manipulations to induce his kind of quantum phenomena, which can introduce unwanted heating, decoherence, or o her negative side effects. In the quest fo**a versatile and more robust platform**, ICFO researchers **Pavel P. Popov** and **Dr. Joana Fraxanet**, led by **ICREA Prof. Maciej Lewenstein,** and in collaboration with ICFO Alumnus Dr. Luca Barbiero from the Politecnico di Torino, have presented a new approach in Physical Review Letters that overcomes such limitations. ? Their proposal requires only two main ingredients: a cloud of molecules and light. ï¿? By scattering a laser beam off these molecules, we can create a controllable environment or photons that mimics the behavior of electrons in a solid material,ï¿½ explains Pavel P pov, first author of the article. The molecules in the cloud, however, must be distributed in a particular way. The researchers can then tune how the scattered photons propagat and interact by carefully controlling and modifying this spatial distribution. ï¿½This setup s able to simulate systems that are notoriously hard to simulate numerically in a very ve satile manner,ï¿½ adds the re

earcher. Indeed, the team theoretically proved that, with the appropriate adjustments, exotic physical phenomena can emerge, includi**non-local couplings**, **geometrical frustration**, and **even artificial magnetic-like fields**, which affect light's motion similar to how real magnetic fields affect electrons. If experimentally realized, their model could become an ideal playground for exploring chiral superfluids, exotic phase transitions, topological phases of matter, and other yet-undiscovered quantum phases. According to Prof. Maciej Lewenstein, lead researcher of the study: ï¿½Understanding the physics this kind of systems host can advance technologic l progress that could, for example, help us building superconductors at room temperature.ï

Reference:

Pavel P. Popov and Joana Fraxanet and Luca Barbiero and Maciej Lewenstein, Geometrical frustration, power law tunneling and nonlocal gauge fields from scattered light, Phys. Rev. Lett. **136**, 103403 (2026).
DOI: https://doi.org/10.1103/hndj-8tj1

Acknowledgements:

ICFO-QOT group acknowledges support from: European Research Council AdG NOQIA; MCIN/AEI (PGC2018-0910.13039/501100011033, CEX2019-000910-S/10.13039/501100011033, Plan National FIDEUA PID2019-106901GB-I00,

ICFO

Plan National STAMEENA PID2022-139099NB, I00, project funded by
MCIN/AEI/10.13039/501100011033 and by the ï¿½European Uni
n NextGenerationEU/PRTRï¿½ (PRTR-C17.I1), FPI); QUANTERA MAQS PCI2019-11182
-2; QUANTERA DYNAMITE PCI2022-132919, QuantERA II Programme co-funded by Euro
ean Union's Horizon 2020 program under Grant Agreement No 101017733; Ministry for Dig
tal Transformation and of Civil Service of the Spanish Government through the QUANTUM
NIA project call - Quantum Spain project, and by the European Union through the Recov
ry, Transformation and Resilience Plan - NextGenerationEU within the framework of the Dig
tal Spain 2026 Agenda; Fundacio Cellex; Fundacio Mir-Puig; Generalitat de Catalunya (Euro
ean Social Fund FEDER and CERCA program, AGAUR Grant No. 2021 SGR 01452, Quantum
CAT U16-011424, co-funded by ERDF Operational Program of Catalonia 2014-2020); Barce
ona Supercomputing Center MareNostrum (FI-2023-3-0024); Funded by the European Un
on. (HORIZON-CL4-2022-QUANTUM-02-SGA PASQuanS2.1, 101113690, EU Horizon
020 FET-OPEN OPTOlogic, Grant No 899794, QU-ATTO, 101168628), EU Horizon Europe Pro
ram (This project has received funding from the European Union's Horizon Europe research
and innovation program under grant agreement No 101080086 NeQSTGrant Agree
ent 101080086 - NeQST); ICFO Internal ï¿½QuantumGaudiï¿½ project; European Union's
Horizon 2020 program under the Marie Sklodowska-Curie grant agreement No 847648
P.P.P. acknowledges also support from the ï¿½Secretaria d'Universitats i Recerca del D
partament de Recerca i Universitats de la Generalitat de Catalunyaï¿½ under grant 2024 FI
3 00390, as well as the European Social Fund Plus. L. B. acknowledges financial support with
n the DiQut Grant No. 2022523NA7 funded by European Union- Next Generation EU, PRIN
022 program (D.D. 104- 02/02/2022 Ministero dell'Universita e della Ricerca).