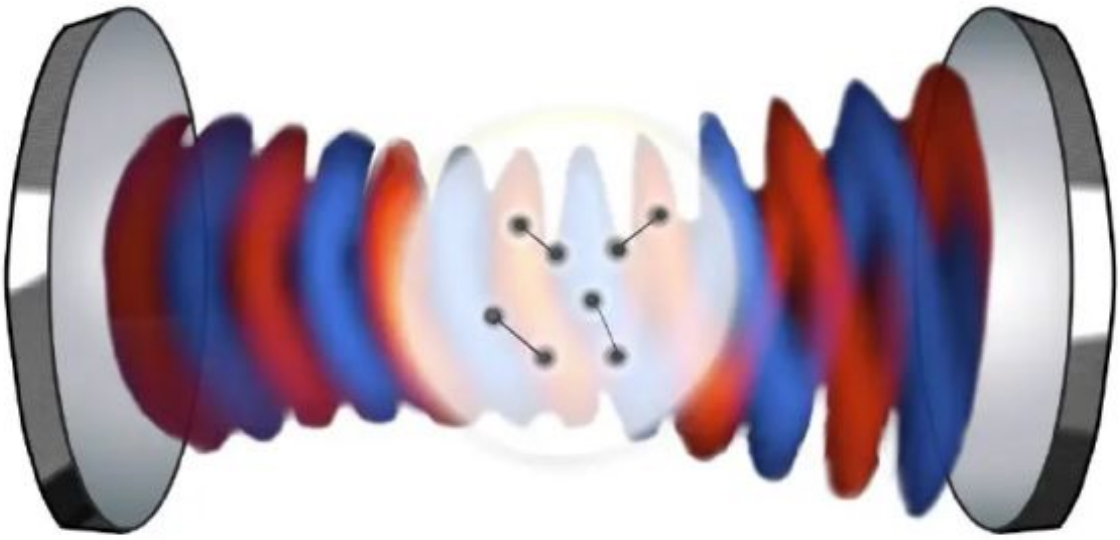

# Playing with light and molecules: a versatile platform for exploring exotic quantum matter

## 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.

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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 i¿½cleani¿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 for 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. i¿? 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,i¿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. i¿½This setup s able to simulate systems that are notoriously hard to simulate numerically in a very ve satile manner,i¿½ adds the re earcher. Indeed, the team theoretically proved that, with the appropriate adjustments, exotic physical phenomena can emerge, including **nonlocal 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: i¿½Understanding the physics this kind of systems host can advance technologic l progress that could, for example, help us building superconductors at room temperature.i

**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).
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