Master 2 internship - Synthetic Photonic Matter with phase-transition engineering in a Quantum Fluid of Light

Overview

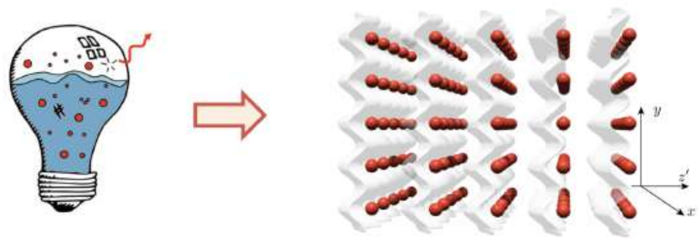
Institution: Sorbonne University - Ecole Normale Supérieure - CNRS - Laboratoire Kastler Brossel
Team: Quantum Fluids of Light team - Alberto Bramati, Quentin Glorieux, Hanna Le Jeannic
Location: Jussieu campus. Paris, France
Duration: 3-6 months - followed by a ERC-funded PhD
Websites: www.quantumoptics.fr and www.quentinglorieux.fr

Quantum fluids of light

Photons are great carriers of information but they usually don't interact with one another. Atoms interact but are hard to manipulate and do not benefit from the toolbox of quantum optics for detecting quantum fluctuations and entanglement [1]. Many approaches have been proposed to **marry these two systems for quantum simulation of condensed matter with strongly interacting photons**, but to date, the realization of large-scale synthetic materials made of optical photons is still missing.

Our team targets this exciting goal, namely **the creation of Synthetic Photonic Matter.**

This ambitious goal relies on our original approach of engineering **a quantum phase transition in a quantum fluid of light.** Indeed, it has been realized that, under suitable circumstances, photons can acquire an effective mass and will behave as a quantum fluid of light with photon-photon interactions. Striking experimental demonstrations of superfluidity [2, 3], analogue gravity [4, 5] and quantum hydrodynamics effects such as quantized vortices [**?**, 6] and solitons [7] have been performed using fluids of light. The current situation is then; we have a superfluid of light (left part of the image below) and we want to create Syntehtic Photonic Matter (right part of the image).



Graphical abstract: a quantum fluid of light is turned into a 3D photonic Mott insulator

Internship Description

Building on these experiments done by the LKB group, we propose to use **a platform based on atomic cloud of Rubidium** to study quantum fluids of light in a new regime. Specifically, we will investigate **the superfluid to Mott insulator transition for light propagating in a dense cold atomic cloud.** In this regime, photons will follow an evolution similar to ultracold atomic quantum gases and our original hypothesis is that a fluid of light should undergo the same phase transition, driven by quantum fluctuations [8, 9], as quantum gases do, and therefore a many-body state of light will emerge from this transition.

Key Responsibilities

As a member of the quantum fluids of light team you will be in charge to

- Design and build a novel cold-atoms setup to explore the physics of fluids of light in the strong interaction regime.
- Collaborate with other team members to conduct experiments and data analysis on already working setups in hot atomic vapors.

Impact of the project

At the fundamental level, **a Mott insulator state of light** allows for exploring truly quantum effects such as the emergence of analogue of phase transition in non-equilibrium systems, the presence of quantum depletion and pre-thermal states and the entanglement dynamics in many-body systems. On the applied side, a photonic Mott insulator is **a giant source of single photons (or any Fock state)** with potentially several hundreds of lattice sites delivering tunable photon number-states in parallel. It will be a game changer for scalability issues in **photonics quantum technologies.**

How to Apply - Contact Us

We are offering **an internship opportunity (followed by an ERC-funded PhD)** to expand the capabilities of this platform to a new level by increasing by many orders of magnitude the effective photon-photon interactions and enter **the strong interaction regime**.

For inquiries or more information about this internship or to apply for this internship, please contact us directly at quentin.glorieux@lkb.upmc.fr.

Quantum fluids of light group at LKB

We are a group of friendly and welcoming scientists and we aim to create **an inclusive and supportive research environment.** We strongly believe in the value of diversity and inclusion in the field of quantum physics and we encourage **women and/or individuals from underrepresented minority groups** to apply for this internship.

References

[1] Q. Glorieux, T. Aladjidi, P. D. Lett, and R. Kaiser, "Hot atomic vapors for nonlinear and quantum optics," *New Journal of Physics*, vol. 25, no. 5, p. 051201, 2023.

[2] Q. Fontaine, T. Bienaimé, S. Pigeon, E. Giacobino, A. Bramati, and Q. Glorieux, "Observation of the bogoliubov dispersion in a fluid of light," *Physical review letters*, vol. 121, no. 18, p. 183604, 2018.

[3] C. Piekarski, W. Liu, J. Steinhauer, E. Giacobino, A. Bramati, and Q. Glorieux, "Measurement of the static structure factor in a paraxial fluid of light using bragg-like spectroscopy," *Physical Review Letters*, vol. 127, no. 2, p. 023401, 2021.

[4] M. J. Jacquet, L. Giacomelli, Q. Valnais, M. Joly, F. Claude, E. Giacobino, Q. Glorieux, I. Carusotto, and A. Bramati, "Quantum vacuum excitation of a quasinormal mode in an analog model of black hole spacetime," *Physical Review Letters*, vol. 130, no. 11, p. 111501, 2023.

[5] J. Steinhauer, M. Abuzarli, T. Aladjidi, T. Bienaimé, C. Piekarski, W. Liu, E. Giacobino, A. Bramati, and Q. Glorieux, "Analogue cosmological particle creation in an ultracold quantum fluid of light," *Nature Communications*, vol. 13, no. 1, p. 2890, 2022.

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[7] T. Bienaimé, M. Isoard, Q. Fontaine, A. Bramati, A. Kamchatnov, Q. Glorieux, and N. Pavloff, "Quantitative analysis of shock wave dynamics in a fluid of light," *Physical Review Letters*, vol. 126, no. 18, p. 183901, 2021.

[8] M. Abuzarli, N. Cherroret, T. Bienaimé, and Q. Glorieux, "Nonequilibrium prethermal states in a two-dimensional photon fluid," *Physical Review Letters*, vol. 129, no. 10, p. 100602, 2022.

[9] Z. Li, F. Claude, T. Boulier, E. Giacobino, Q. Glorieux, A. Bramati, and C. Ciuti, "Dissipative phase transition with driving-controlled spatial dimension and diffusive boundary conditions," *Physical Review Letters*, vol. 128, no. 9, p. 093601, 2022.