Quantum Fluids of Light: an introduction

Iacopo Carusotto[1]

[1]*INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, Povo, Italy*
E-mail: iacopo.carusotto@unitn.it

In these seminars I will introduce the audience to the general concept of quantum fluid of light. In suitable optical configurations, photons acquire a finite effective mass and experience significant binary interactions mediated by the optical nonlinearity of the underlying medium. As a result, the many photons forming an optical field can be seen as a gas of massive and interacting Bose particles displaying collective many-body effects. In addition to its intrinsic interest, this novel point of view on optics will hopefully shine new light on general physical ideas that are going to be covered in other lectures of this School.

Assuming an elementary knowledge of undergraduate statistical physics, I will discuss the new features shown by a fluid of light as a result of its intrinsic non-equilibrium nature: an external pumping is in fact necessary to compensate for unavoidable radiative and non-radiative loss channels and/or take into account light propagation. More than being just an hindrance, this crucial novelty opens the way to a number of new phenomena and unexpected possibilities.

I will concentrate on two most promising configurations, namely (i) planar cavities or coupled cavity arrays where photons follow a driven-dissipative dynamics, and (ii) light propagation in cavityless bulk media where propagation along z can be described as a temporal evolution and time t plays the role of an extra spatial coordinate.

In the first part of the lectures, I will discuss the physics of weakly interacting gases for which a classical mean-field description in terms of Maxwell's equations with a non-linear polarization leads to (generalized) Gross-Pitaevskii equations. Experiments illustrating superfluid properties of the fluid of light will be reviewed and open questions will be highlighted. In particular, the rich physics of small quantum fluctuations around such mean-field will be briefly mentioned, including exciting modern developments towards analog models of gravitational physics.

In the second part, I will shift my focus on the study of topological effects in fluids of light. After a short review of different platforms in which integer quantum Hall physics has been explored in optics, I will introduce the audience to the most exciting challenges. As most remarkable examples, I will present how the concept of synthetic dimension is opening the way towards the realization of quantum fluids in dimension higher than 3 and how its natural connection to frequency multiplexing could have a tremendous impact on photonics applications. Then, I will discuss the on-going challenge of generating strongly correlated states of light in strongly nonlinear media, e.g. in the photon blockade limit. In doing this, a special emphasis will be given to fractional quantum Hall liquids of light and their speculative applications to topological quantum computing.

References

[1] I. Carusotto and C. Ciuti, *Quantum Fluids of Light*, Rev. Mod. Phys. **85**, 299 (2013)

[2] I. Carusotto, *Circumnavigating an ocean of incompressible light*, Il Nuovo Saggiatore (Magazine of the Italian Physical Society). Available as arXiv:1212.6161.