PhD fellowship

Quantum Fluids of Light

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Expected Starting date: Autumn 2016.

This 3-years theoretical PhD fellowship takes place within the ANR[3] project "**Quantum Fluids of Light**" (10/2016-02/2020), coordinated by Guillaume Malpuech from Institut Pascal, Clermont-Ferrand (IP). The project is the result of a long-standing collaboration which led in the last decade to a large amount of publications in high-impact journals (Nature, Science, Phys. Rev. Lett.). It involves the Laboratory Kastler and Brossel (LKB), Laboratory of Photonics and Nanostructures (LPN), both in Paris, and the Institut Néel (IN) in Grenoble. The samples will be fabricated in LPN and IN and studied experimentally in LKB, LPN and IN. The theoretical part of the project will be essentially performed by IP, mainly by the recruited PhD student. This position is a unique opportunity to work in a collaborative research environment in a direct connection will leading groups at the world scale.

Expected background of the fellow:
The PhD will involve many different areas of physics, which will allow the PhD student to acquire a very wide scientific background and will ensure an excellent employability for a scientific career. The candidate should possess a Master of Physics with a good knowledge in one of the following fields (several being better): Solid State Physics, Photonics, Quantum Physics, Numerical Simulation, Theoretical Physics.

Project Summary:

Quantum coherence in interacting boson systems is at the origin of striking effects, such as Bose Einstein Condensation (BEC), superfluidity, and quantum turbulence. Quantum fluids allow to emulate complex physical systems which cannot be accessed experimentally, as pointed out, for example, in the seminal book of G. Volovik "The Universe in an Helium droplet" [1] or by the recent works on Black Hole analogs [2]. Similarly, the concept of quantum simulator and the emulation of complex Hamiltonians is in the focus of the cold atom community for a decade. The mixed light-matter states, resulting from the strong exciton-photon coupling in semiconductor microcavities (polaritons), allow producing quantum fluids of light (QFL). Indeed, polaritons self-interact thanks to their excitonic part, whereas their photonic part allows their resonant excitation and detection, using the most advanced optical techniques. These techniques allow, with a remarkable simplicity, to fully control the spatial distribution of the density, phase, velocity of the created QFL, and to record directly the evolution of these parameters. These key features have allowed major findings over the

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1 **Dmitry Solnyshkov** (MCF UBP), 35 years old, Maître de Conferences (Assistant Professor) at Institut Pascal and University Blaise Pascal. From Web Of Science : 110 research article (including 3 Nat. Phys and 3 Nat. Comm, 22 Phys. Rev. Lett.) cited 2200 times in total, 431 times in 2015, h=27. Co-supervised 4 PhD students.Previously involved in 3 collaborative EU projects and 1 ANR project.

2 **Guillaume Malpuech**, 41 years old, CNRS Senior researcher, Head of the PHOTON department of IP (60 researchers). He is a known theoretician in the field of polaritonics with a large collaborative activity with leading experimental groups. From WOS: 190 articles, (64 PRB/A, 29 PRL, 1PRX, 4 Nat. Phys., 3 Nat. Com.) cited 4600 times in total, 586 in 2015; h=42. Co-author of the books "Cavity Polaritons" , Elsevier 2003, and "Microcavities", Oxford University Press. Supervised 9 PhD students. Previously involved in 7 collaborative EU projects, 3 times as node coordinator and once as project coordinator.

3 ANR : Agence Nationale pour la Recherche

last years, with for instance the demonstration of BEC[3] and superfluidity[4], and also with phenomena unique to QFLs, such as the formation of oblique dark solitons [5], or the emergence of magnetic monopole analogues[6]. The project will **provide a breakthrough in the understanding and operation of QFL.** Based on a deep analysis of their distinctive features (inter-particle interactions, spinor and nonequilibrium character), **novel behaviors and phases will be created by engineering the environment experienced by the polaritons and by implementing artificial gauge fields.**
The project is organized around five scientific objectives:

1) **Propagation, superfluidity and quantum turbulence.** We plan to perform a **systematic** study of the superfluid behaviour of a resonantly driven polariton fluid, and in particular, how it interacts with static defect and with phonons, and how superfluidity turns into quantum turbulence.
2) **Propagation in media with controlled disorder landscape.** We will study in 2D systems and honeycomb lattices the interplay between kinetic energy, interaction energy, the dispersion, and disorder with controlled parameters. Regimes of weak localization, anti-localization, Anderson localization, and superfluidity will be demonstrated and quantitatively studied.
3) **Topological excitations in 1D and 2D QFLs: Individual and collective properties**. We will study the nucleation, the dynamical and thermal stability of solitons and half-solitons in 1D, of vortices and half-vortices in 2D, their interaction, and the formation of collective states such as Abrikosov and Wigner lattices.
4) **Bose Einstein Condensation of cavity polaritons.** We will study the mechanism of this phase transition in which a QFL is spontaneously generated, its interplay with the solid-state environment (phonons, excitons), and its nonequilibrium features.
5) **Quantum simulation with polaritons.** We will exploit the specificity of the QFL, especially the direct access to the complete wave-function, to emulate systems of very different nature. We will simulate astrophysical objects such as 1D and 2D black holes as we theoretically proposed [7]. A principle scheme of 1D Black hole analog implementation is shown on the figure 1. We will also simulate condensed matter systems such as topologically non-trivial bands that we theoretically proposed last year [8] (Quantum Hall and Quantum Anomalous Hall effects for light).

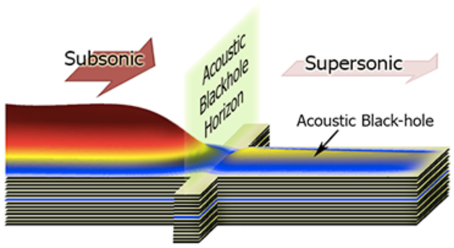

Fig. 5. Scheme of the polariton acoustic black hole realized in a wire microcavity at LPN.

The partners possess complementary skills which are all essential for the accomplishment of the project. New theoretical insights on QFL will be developed by IP. A Unique new generation of CdTe microcavities and etched GaAs structures will by fabricated by IN and LPN. Complementary state of the art optical spectroscopy of the fabricated samples will be performed by LKB, LPN, and IN. This consortium has obtained pioneering results in polaritonics in the past years and is particularly well positioned to tackle the proposed research plan and to obtain outstanding results, which will be valorized by publication in high profile journals as appropriate.

References:

[1] G.E. Volovik, *The Universe in a Helium Droplet*, Clarendon Press, Oxford (2003).
[2] W.G. Unruh, **Phys. Rev. Lett**. 46, 1351 (1981).
[3] J. Kasprzak et al., **Nature 443**, 409 (2006).
[4] A. Amo et al.,**Nature Physics 5**, 805, (2009).
[5] A. Amo et al., **Science, 332**, 1167 (2011).
[6] R. Hivet et al, **Nature Physics 8**, 724 (2012).
[7] D. Solnyshkov, H. Flayac, G. Malpuech, **Phys. Rev. B. 84**, 233405 (2011).
[8] A. Nalitov, D. Solnyshkov, G. Malpuech, **Phys. Rev. Lett. 114**, 116401 (2015).