Theory of Polariton Condensates

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The physics of quantum fluids of light and the related field of nonequilibrium condensation experience dynamic development in the recent years [1]. The experimental realizations of exciton-polariton condensates ten years ago [2] provided vast possibilities for investigating nonequilibrium quantum systems on an entirely new level, important for understanding of fundamentals of nonequilibrium physics. At the same time, prototypes of devices for applications, such as low-threshold polariton lasers, quantum-enhanced interferometers or low-loss polariton circuits, have been realized.

I will briefly describe the basic theory of exciton-polaritons as well as some of the most interesting experimental realizations and future directions. Commonly used theoretical models based on the mean-field generalized Gross-Pitaevskii equation and its extensions including the effects of quantum fluctuations will be discussed.

In the second part of the talk I will describe our work related to the recent observations of instabilities of non-equilibrium exciton-polariton condensates. We demonstrate the first observation of the long-sought reservoir-induced instability in a nonresonantly pumped condensate [3]. Without any free parameters, we find an excellent agreement between the experimental data and numerical simulations of the open-dissipative Gross-Pitaevskii equation, which allows us to dismiss the competing theoretical model based on the complex Ginzburg-Landau equation. In the case of resonant excitation, the observation of the real-space collapse of the polariton fluid was explained by the effective attractive interactions mediated by the lattice phonons [4]. The observation of instabilities in polariton condensates may fundamentally change our understanding of superfluidity, coherence, and critical properties of these systems.

[1] I. Carusotto and C. Ciuti, *Rev. Mod. Phys.* **85**, 299 (2013).
[2] J. Kasprzak, M. Richard, S. Kundermann, A. Baas, P. Jeambrun, J. M. J. Keeling, F. M. Marchetti, M. H. Szymańska, R. Andre, J. L. Staehli, et al., *Nature* **443**, 409 (2006).
[3] N. Bobrovska, M. Matuszewski, K. S. Daskalakis, S. A. Maier, and S. Kéna-Cohen, arXiv:1603.06897.
[4] L. Dominici, M. Petrov, M. Matuszewski, D. Ballarini, M. De Giorgi, D. Colas, E. Cancellieri, B. Silva Fernandez, A. Bramati, G. Gigli, A. Kavokin, F. Laussy, and D. Sanvitto, *Nature Commun.* **6**, 8993 (2015).