Condensation of light – from fundamental physics to optical computers

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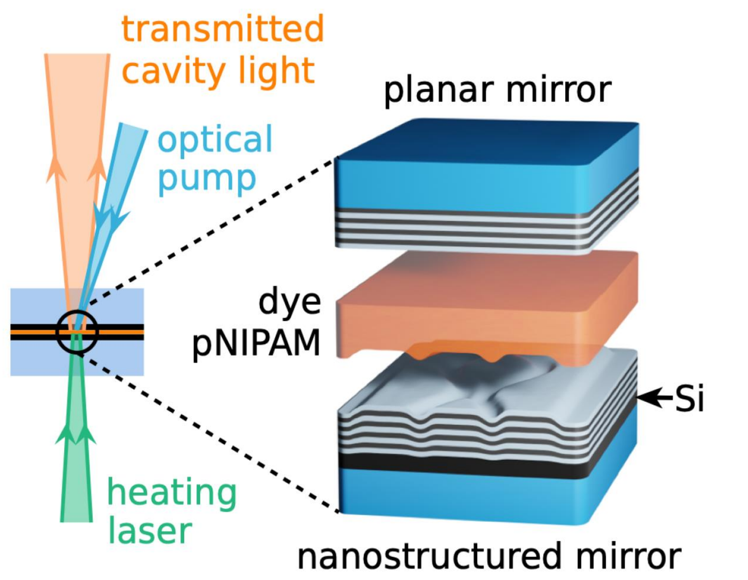
Bose-Einstein Condensate platform

Here, we present **photon Bose-Einstein condensate (pBEC)** platform for spin-glass simulations.

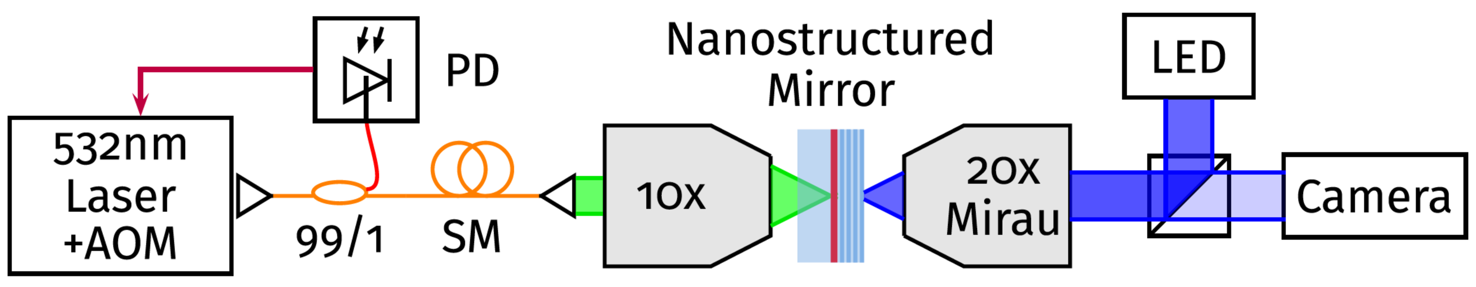
The **optical pump** via interaction with dye creates macroscopic number of photons in ground state – a condensate.

The **heating laser** is used to change the refractive index of the polymer, hence in situ changing the potential landscape.



Mirror nanostructuring

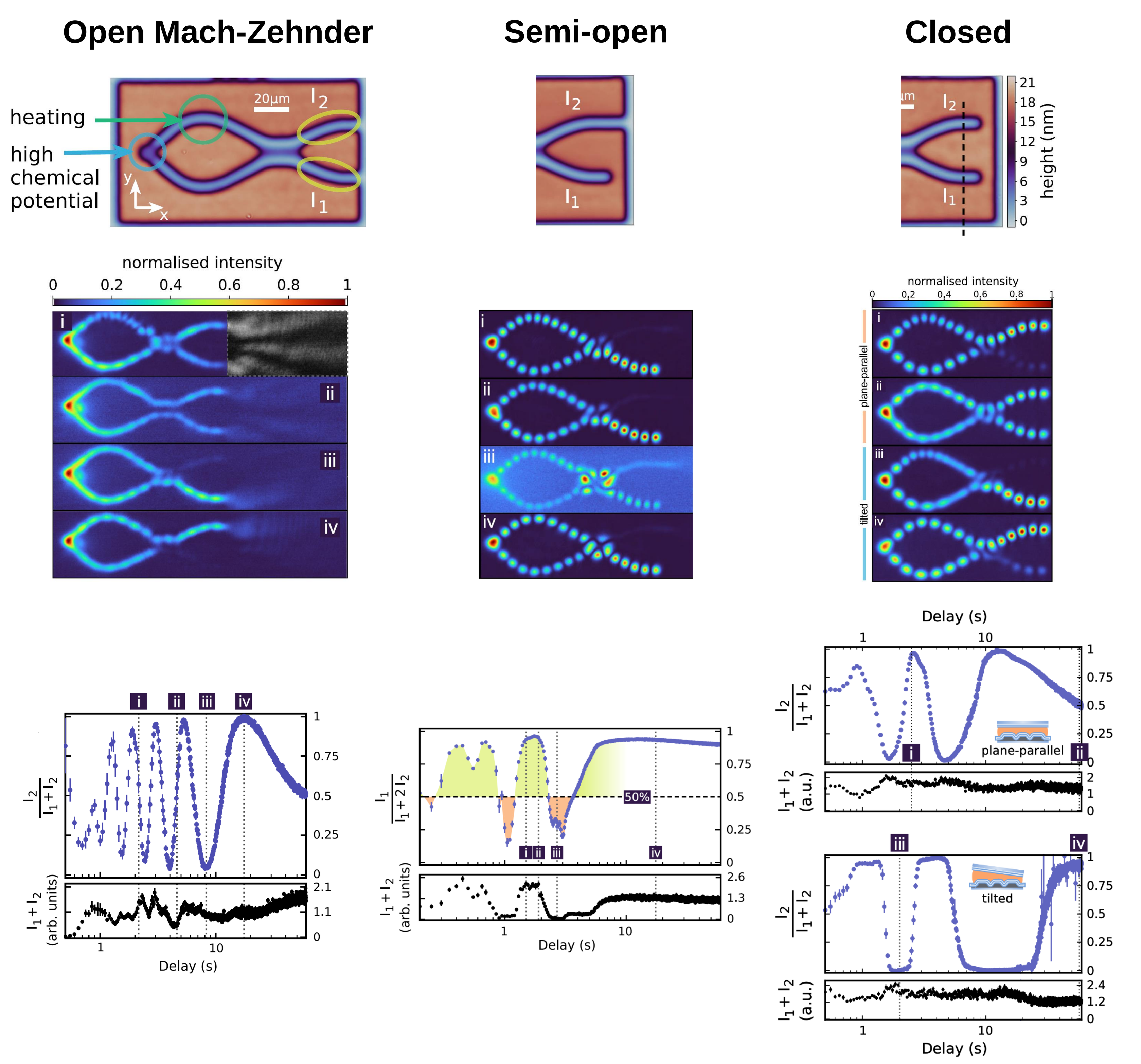
Direct laser writing setup



The surface of ultra-high finesse mirror may be accurately nanostructured by **direct laser writing** [1]. This enables to construct precise and uniform height profiles with sub-nanometer resolution.

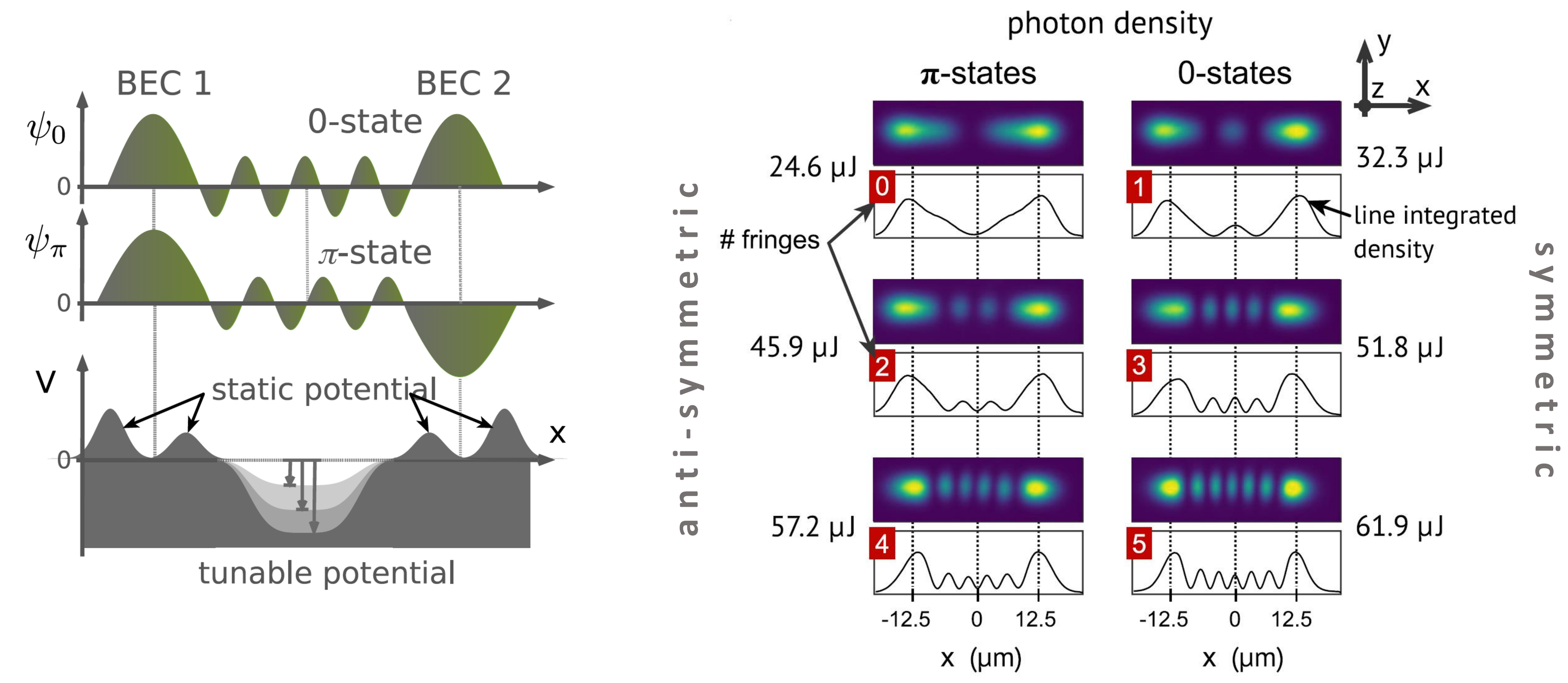
pBEC in an interferometer

We investigate the pBEC in an environment with controlled dissipation and feedback. We have found that pBECs naturally try to **avoid particle loss** and destructive interference [3].

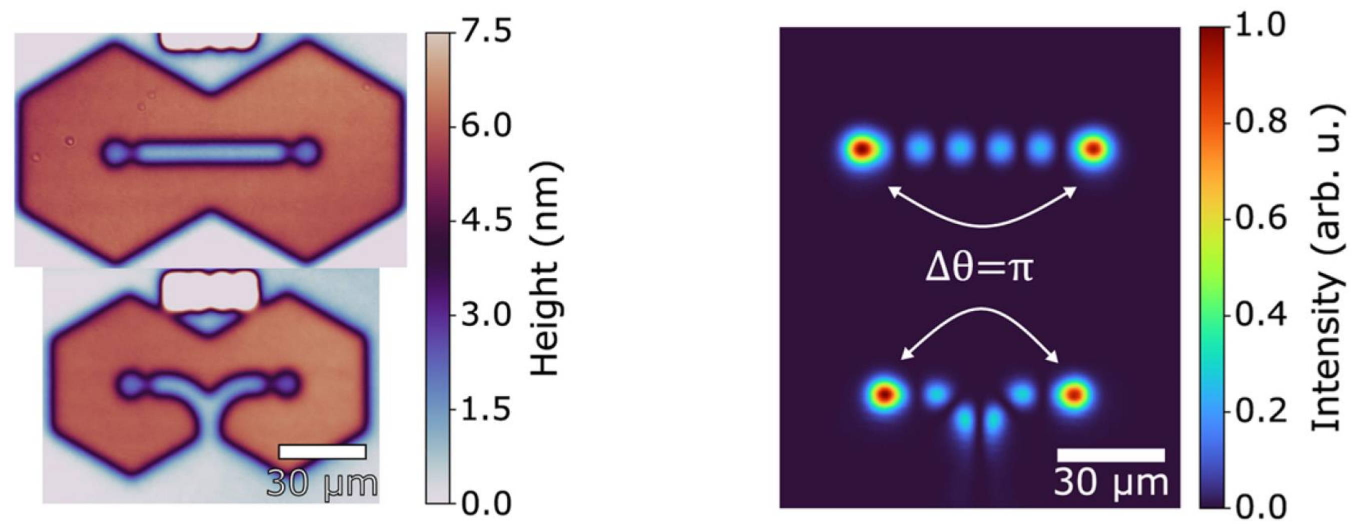


Controlling coupling between condensates

By addressing controlled amount of heat we are able to **adjust** strength and sign of **coupling** between pBECs. This system behaves as a controllable Josephson junction [1].



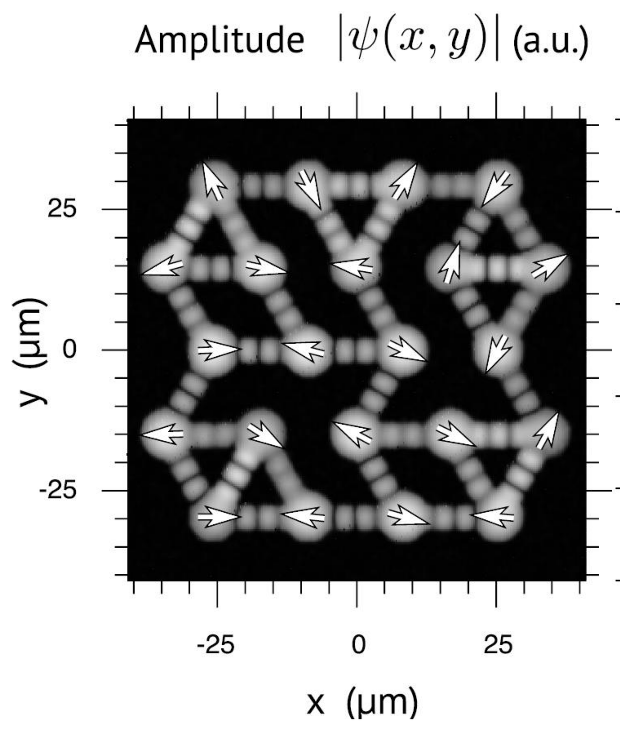
Adding losses to interaction between pBECs transforms coupler into **dissipative** and makes **antisymmetric states more favorable** [2].

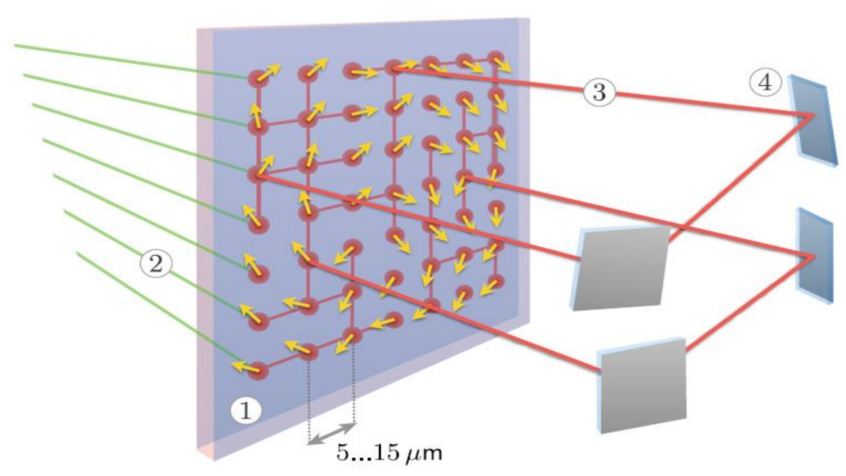


Both types of couplings can be used as a **building block** for analog spin-glass simulator.

Outlook

Finding a ground state of all-negatively coupled network of pBECs is equivalent to finding a solution for problems from **NP-complete** class which are **hard to solve** even for conventional supercomputers.





At current state of the project our group is **mainly focused on scaling** number of controllably interacting condensates from only few to potentially hundreds.

Network of pBECs is analogous to **XY spin model** governed by following Hamiltonian:

$$H = -\sum_{i,j=1}^{N} J_{ij} \cos(\theta_i - \theta_j) - \sum_{i=1}^{N} h_i \cos\theta_i$$

[1] Vretenar, Mario, et al. "Controllable Josephson junction for photon Bose-Einstein condensates." Physical Review Research 3.2 (2021)
[2] Vretenar, Mario, Chris Toebes, and Jan Klaers. "Modified Bose-Einstein condensation in an optical quantum gas." Nature communications 12.1 (2021)
[3] Toebes, Chris, Mario Vretenar, and Jan Klaers. "Dispersive and dissipative coupling of photon Bose-Einstein condensates." Communications Physics 5.1 (2022)

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