Seminar announcement

Tuesday, September 9, 2025
1:30 pm
WSI, Seminar room S 101
Exclusively in person

“Liquid light in synthetic dimensions: Toward a new class of frequency combs”

The study of light dynamics in the frequency domain has been pivotal for applications in metrology and communications. One of the most impactful states is the optical frequency comb—a broadband light state where frequencies are equally spaced. These discrete frequencies can be mapped onto a lattice in a synthetic frequency space, where multiple coupling scheme have been proposed to explore novel state of light [1]. In principle, these schemes could expand the versatility of frequency combs, but the studies present linear systems that lack a self-reinforcing mechanism. As such, these cannot serve as efficient steady-state sources, when such sources requires both frequency proliferation and nonlinear stabilization. Interestingly, recent advances in semiconductor-based frequency-comb sources have shown that when the gain recovery time becomes very short [2], the dynamics of light in the frequency domain become radically different [3-6], and can serve as a new nonlinear stabilization mechanism.

In my talk, I will present the exploration of light dynamics in a discrete frequency space, when gain recovery times are the fastest timescale in the system [7,8]. I will show that light traveling through a medium with fast gain saturation transforms it into a type of liquid, which forces coherent dynamics despite destabilization processes, for example quenching or dephasing. This liquid state of light allows to explore fully the synthetic lattice in the frequency space, reaching its maximal limit given by the linear system. Such a platform not only advances our understanding of quench dynamics in non-equilibrium systems, but can also lead to innovative quantum inspired devices, like the recently discovered quantum walk comb source [8].

[1] Yu, Danying, et al. "Comprehensive review on developments of synthetic dimensions." Photonics Insights 4.2 (2025).
[2] U. Senica, A. Dikopoltsev, et al., “Frequency-Modulated Combs via Field-Enhancing Tapered Waveguides”, Laser Photonics Rev, 2300472 (2023).
[3] J. B. Khurgin, et al. "Coherent frequency combs produced by self frequency modulation in quantum cascade lasers." APL 104.8 (2014).
[4] N. Opačak, et al., “Theory of frequency-modulated combs in lasers with spatial hole burning, dispersion, and Kerr nonlinearity” Phys. Rev. Lett. 123, 243902 (2019).
[5] D. Burghoff, "Unravelling the origin of frequency modulated combs using active cavity mean-field theory." Optica 7.12 (2020): 1781-1787.
[6] M. Piccardo, et al. "Frequency combs induced by phase turbulence." Nature 582.7812 (2020): 360-364.
[7] A. Dikopoltsev, et al. "Collective quench dynamics of active photonic lattices in synthetic dimensions." Nature Physics (2025): 1-7.
[8] I. Heckelmann*, M. Bertrand*, A. Dikopoltsev*, et al., “Quantum walk comb in a fast gain laser”, Science 382, 434-438 (2023).

Dr. Alexander Dikopoltsev
ETH Zürich
Institute for Quantum Electronics, Quantum Optoelectronics Group
Zürich, Switzerland

Dr. Alexander Dikopoltsev is a postdoctoral research fellow and lecturer at the Institute of Quantum Electronics, ETH Zurich. He earned his Ph.D. in nonlinear photonics and laser science from the Technion – Israel Institute of Technology in 2022, following dual bachelor's degrees in Electrical Engineering and Physics. Dr. Dikopoltsev's research spans nonlinear optics, topological photonics, time-varying media, optoelectronic devices, and frequency-comb sources. His current work focuses on leveraging photonic lattice schemes to control light in quantum cascade laser (QCL) frequency-comb devices, pushing the boundaries of light-matter interaction for advanced photonic applications.