# Observing hydrodynamic phenomena with light via analogy between quantum gases and nonlinear optics

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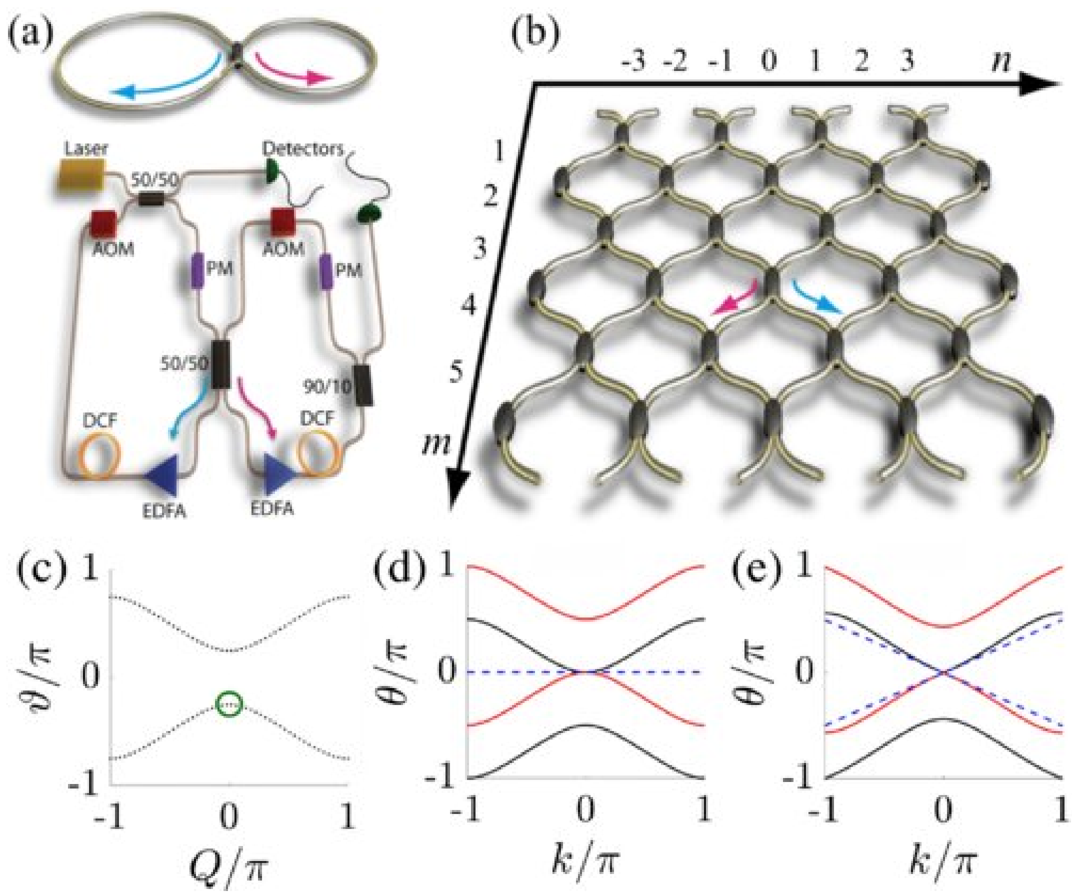


Figure 1. (a) Optical pulses propagating in two nonlinear, coupled fiber loops of slightly different lengths, are used to explore nonlinear light evolution in the (1+1)D lattice, shown schematically in (b). In this mapping, the light intensity is a function of the discrete position in the lattice, *n*, and evolves with respect to the discrete time step, *m*. Completing a round-trip in the short (long) loop in the real system in (a) corresponds to traveling from northeast (northwest) to southwest

(southeast) in the effective lattice in (b). Acousto-optical modulators (AOM) and erbium doped fiber amplifiers (EDFA) are used to compensate for losses. A phase modulator (PM) in each loop allows us to induce arbitrarily designed space- and time-dependent potentials. (c) The corresponding photonic bands in the linear (Γ=0) regime. (d),(e) The Bogoliubov dispersions (2) on top of a condensate located at Q=0 in the lower band [circle in (c)] for (d) linear and (e) nonlinear (ΓI0=0.2) systems. The slope of the straight blue dashed line indicates the speed of sound (3). The red (black) color of each curve indicates the positive (negative) value of the band's Bogoliubov norm. Credit: DOI: 10.1103/PhysRevLett.127.163901

A team of researchers from Friedrich-Schiller-University Jena, Universit di Trento and the University of Birmingham has developed a way to "listen" to sounds generated in a fluid of light. In their paper published in the journal *Physical Review Letters*, the group describes their work and its possible use as a new way to study fluids.

Prior research has shown that under normal circumstances, light travels in a straight line and is not affected by other rays of light. In this new effort, the researchers have created a system where pulses of light interact and together they behave in ways that suggest a superfluid.

The work by the team involved building a device capable of simulating the behavior of a superfluid—one that flows without slowing due to friction—and then testing it by listening to the "sound" that was generated. The device was made of fiber cables that were formed into a mesh in such a way as to allow the use of "synthetic" dimensions—using temporal degrees of freedom as a stand-in for spatial degrees of freedom. The mesh was created by first building pairs of cables looped into circles of two different sizes and then connecting them together with a beam splitter. A light pulse would then be spilt and the results sent through both of the two loops. Under such an arrangement, light would propagate through the shorter loop faster than through the longer loop—thus the two pulses would be time-shifted respective to one another with the subintervals playing the role of effective spatial locations. The team then connected multiple loop pairs together to create a mesh. Under such a scenario, multiple pulses of light overlapped within a given loop and in so doing, changed the behavior of the system from mimicking a gas to mimicking a superfluid.

The researchers then measured the "speed" of the "sound" generated by the system as the light moved through it like a liquid. In their system, "sound" was represented by waves propagating in a synthetic dimension. Thus, their speed measurement was actually a measurement of simulated ripples propagating through the mesh—and it agreed with hydrodynamic theory, showing their approach was working as intended. The team also tested the possibility of dragging a simulated object through the system. They suggest their approach could be used as a new way to study fluid behavior.

**More information:** Martin Wimmer et al, Superfluidity of Light and its Breakdown in Optical Mesh Lattices, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.127.163901