Nonlinear hydrodynamics on a chip: wave breaking and multisoliton fission in a superfluid waveflume

Christopher G Baker, Walter W Wasserman, Matthew T Reeves, Raymond A Harrison, Igor Marinkovic, Glen I Harris, and Warwick P Bowen

ARC Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, St Lucia, QLD 4072, Australia

In this talk I will present research interfacing cavity optomechanics and superfluid physics for the study of nonlinear wave phenomena.

Building upon our previous work in superfluid optomechanics [1], I will present a novel sensor architecture formed by covering nanofabricated silicon photonic crystal beams with a thin superfluid helium-4 film. This creates an optically addressable quasi-one-dimensional wave tank containing a few femtoliters of superfluid helium, upon which waves can be generated, propagate and be readout.

Superfluid helium's characteristics present a unique opportunity for the study of nonlinear wave propagation. Indeed, thanks to superfluid helium's vanishing viscosity, the depth of the film h can readily be made as small as a few nanometers without wave attenuation–something impossible to do with classical fluids. Our platform thus enables us to generate waves whose aspect ratio (defined as the wavelength over depth λ/h) exceeds 10,000:1, two orders of magnitude larger than that achievable in the world's largest wave tanks and exceeding that of the most extreme terrestrial phenomena such as tsunamis. This, combined with our recently developed ability to engineer strong fountain pressure forces [2], now allows us to combine within a single device high spatial and temporal resolution along with strong actuation capabilities.

Leveraging these unique characteristics, I will show how our superfluid wave tank enables us to generate and measure (within a sub-millimetre-sized device in a laboratory setting) a rich variety of superfluid nonlinear wave phenomena for the first time, including wavebreaking, multisoliton fission and optomechanical dissipative solitons [3] - opening up the way for the study of extreme regimes of nonlinear hydrodynamics on a chip.

This work was funded by the U.S. Army Research Office through grants number W911NF17-1-0310 and W911NF-23-1-0117 and the Australian Research Council Centre of Excellence for Engineered Quantum Systems (EQUS, Project No. CE170100009). C.G.B and G.I.H respectively acknowledge Australian Research Council Fellowships DE190100318 and DE210100848.

[1] X. He et al., Nature Physics 16, 4 (2020); Y. P. Sachkou et al., Science 366, 1480 (2019), G. Harris et al, Nature Physics 12, 8 (2016) ; W. W. Wasserman et al., Opt. Express 30, 30822 (2022) ; C. Baker et al., New J. Phys 18, 123025 (2016)

[2] A. Sawadsky et al., Science Advances 9, eade3591 (2023)

[3] J. Zhang et al., Optomechanical Dissipative Solitons, Nature 600, 75 (2021)