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Probing the dynamics of two dimensional superfluids with cavity optomechanics.

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Two dimensional superfluids exhibit a rich range of thermodynamical and quantum behavior, from quantum vortices and turbulence to two dimensional phase transitions. In this talk I will introduce a new approach to probe this physics based on the evanescent interaction between a few-nanometer-thick superfluid helium film and an optical whispering gallery mode microcavity. This enables both sound waves and vortices to be confined to areas four orders of magnitude smaller than has previously been possible in two dimensional superfluid helium, in conjunction with precision optical read-out of the superfluid motion. The increased confinement results in enhanced interactions between the sound waves and both light and vortices. This allows the observation and cooling of thermomechanical fluctuations of superfluid sound waves [1], as well as probing of nonequilibrium vortex dynamics and phonon-vortex interactions. The ability to probe excitations in real time may provide a new approach towards understanding the microscopic behaviour of superfluids, including quantum turbulence, quantum vortices, and two dimensional phenomena such as the Berezinskii-Kosterlitz-Thouless transition. Furthermore, our results present a step towards quantum optomechanics with superfluid films, with the prospect for strong optomechanical coupling [2], femto- to pico-gram effective mass, high mechanical quality factor and strong phonon-phonon interactions. This could potentially enable the realization of macroscopic non-classical states of a superfluid, optomechanics with quantized vortices, and applications in superfluid force and inertial sensing. Other contributors: Glen Harris, David McAuslan, Christopher Baker, Yauhen Sachkou, Xin He and Eoin Sheridan [1] G. I. Harris *et al*, Nature Physics **12**, 788_793 (2016); D. L. McAuslan, PRX **6**, 021012 (2016). [2] C. G. Baker *et al*, arXiv:1609.07265 (2016).