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Cryogenic endoscopic iSCAT microscopy of quantum-vortices

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Turbulence is one of the most elusive topics in physics that remains to be solved. Superfluid helium is a strongly interacting quantum fluid—characterised by a vanishing viscosity—and has been a vastly successful platform in furthering our understanding of turbulent flows in recent years [1]. The dynamics of quantised vortices play an essential role in the classical-to-quantum transition of two-dimensional superfluids, and the quantum turbulence they exhibit. However, the study of these quantised vortices is complicated by their nanoscopic sizes, weak scattering, and the need for cryogenic conditions—leaving standard imaging techniques impractical. Recently, precision sensing of superfluid volumes down to the femto-litre scale has been achieved through several successful indirect techniques [1-2]. However, direct, real-time, non-destructive, and label-free optical sensing of singular vortices in a two-dimensional superfluid is yet to be realised in experiment [1]. Here I will present preliminary results towards overcoming these challenges. Through a novel application of ‘interferometric-scattering’ (iSCAT) nano-particle sensing in a cryogenic endoscopic package, this work promises high-speed and real-time imaging of two-dimensional quantum vortices [3]. In combination with nanofabricated on-chip electrostatic ‘vortex traps’, our sensing platform places historically tantalising investigations of elusive out-of-equilibrium superfluid phenomena—like vortex generation and annihilation, vortex matter, and long-time dynamics—within reach in the lab.

[1] Y. P. Sachkou et al., *Science* 366, 1480 (2019).

[2] A. Sawadsky et al, *Science Advances* 9, eade3591 (2023); X. He et al., *Nature Physics* 16, 4 (2020); A. Kashkanova et al., *Nat. Phys.* 13(1), 74–79 (2017).

[3] A. J. R. MacDonald et al., *Rev. Sci. Instrum.* 86, 013107 (2015); K. Lindfors et al., *Phys. Rev. Lett.* 93, 037401 (2004).

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