CONDENSED MATTER SCIENCES SEMINAR

Professor Makoto Tsubota

Osaka Metropolitan University

Host

Dr Wei Guo

Title

Quantum Hydrodynamics and Turbulence: A Journey from Legacy to Future

Friday, August 14th, 2026

1st Floor – B101

15:00-16:00

Abstract

Quantum hydrodynamics and turbulence (QHT) have been central topics in low-temperature physics for over half a century, spanning superfluid ^{4}He, ^{3}He, and ultracold atomic gases [1]. Their defining feature is the presence of quantized vortices—stable topological defects—that provide a reductionist framework for studying nonlinear, non-equilibrium quantum phenomena beyond the scope of equilibrium statistical mechanics.

I will review the development of QHT, beginning with superfluid helium. Thermal counterflow in superfluid ^{4}He has served as the canonical system, with experiments [2], vortex filament simulations [3], visualization of quantized vortices and normal-fluid motion [4], and studies of two-fluid coupling [5] establishing its dynamics. Recent progress in Kelvin-wave excitation and observation will also be discussed [6].

The talk will then focus on QHT in atomic Bose–Einstein condensates (BECs), where both 3D and 2D quantum turbulence have been realized [7]. Homogeneous turbulence and energy cascades have been observed in box-potential experiments [8], while the high controllability of BECs enables detailed studies of vortex dynamics, reconnections, and multi-component superfluid. I will conclude by outlining current challenges and future directions.

[1] M. Tsubota and K. Kasamatsu, Quantum Hydrodynamics and Turbulence (Oxford University Press, 2025).

[2] W. F. Vinen, Proc. R. Soc. A 242, 493 (1957); J. T. Tough, Superfluid turbulence, in Prog. in Low Temp. Phys., ed. by D. F. Brewer (North-Holland, Amsterdam,1982), Vol. 8, Chap. 3.

[3] K. W. Schwarz, Phys. Rev. B38, 2398 (1988); H. Adachi et al., Phys. Rev. B81,

104511(2010).

[4] G. P. Bewley et al., Nature 441, 588 (2006); A. Marakov et al., Phys. Rev. B 91, 094503(2015).

[5] S. Yui et al., Phys. Rev. Lett. 124, 155301 (2020); S. Yui et al., J. Phys. Soc. Jpn. 94, 043601(2025).

[6] Y. Minowa et al., Nat. Phys.21, 233(2025).

[7] E. A. L. Henn et al., Phys. Rev. Lett. 103, 045301 (2009); G. Gauthier et al., Science 364, 1264 (2019); S. P. Johnstone et al., Science 364, 1267 (2019).

[8] N. Navon et al., Nature 539, 72 (2016); N. Navon et al., Science 366, 382 (2019).

BIO

Makoto Tsubota is internationally recognized as one of the leading researchers in low-temperature physics, especially in quantum hydrodynamics and quantum turbulence. For more than three decades, he has made pioneering contributions to the theory of quantized vortices, superfluid helium, and atomic Bose–Einstein condensates. His work has played a central role in establishing our current understanding of quantum turbulence and its connections to classical turbulence.

He received his Ph.D. from Kyoto University and has held faculty positions at Kochi University, Tohoku University, Osaka City University, and Osaka Metropolitan University, where he is currently a Specially Appointed Professor.

He has published about 200 refereed papers, including many in leading journals such as *Nature*, *Science*, *Nature Physics*, and *Physical Review Letters*. Last year, he co-authored the book *Quantum Hydrodynamics and Turbulence*, published by Oxford University Press, which provides a comprehensive and unifying treatment of this rapidly developing field. He has also served in leadership roles for major international conferences on quantum fluids and low-temperature physics and has received several prestigious awards, including the Osaka Science Prize and the Fluid Science Prize in Japan.