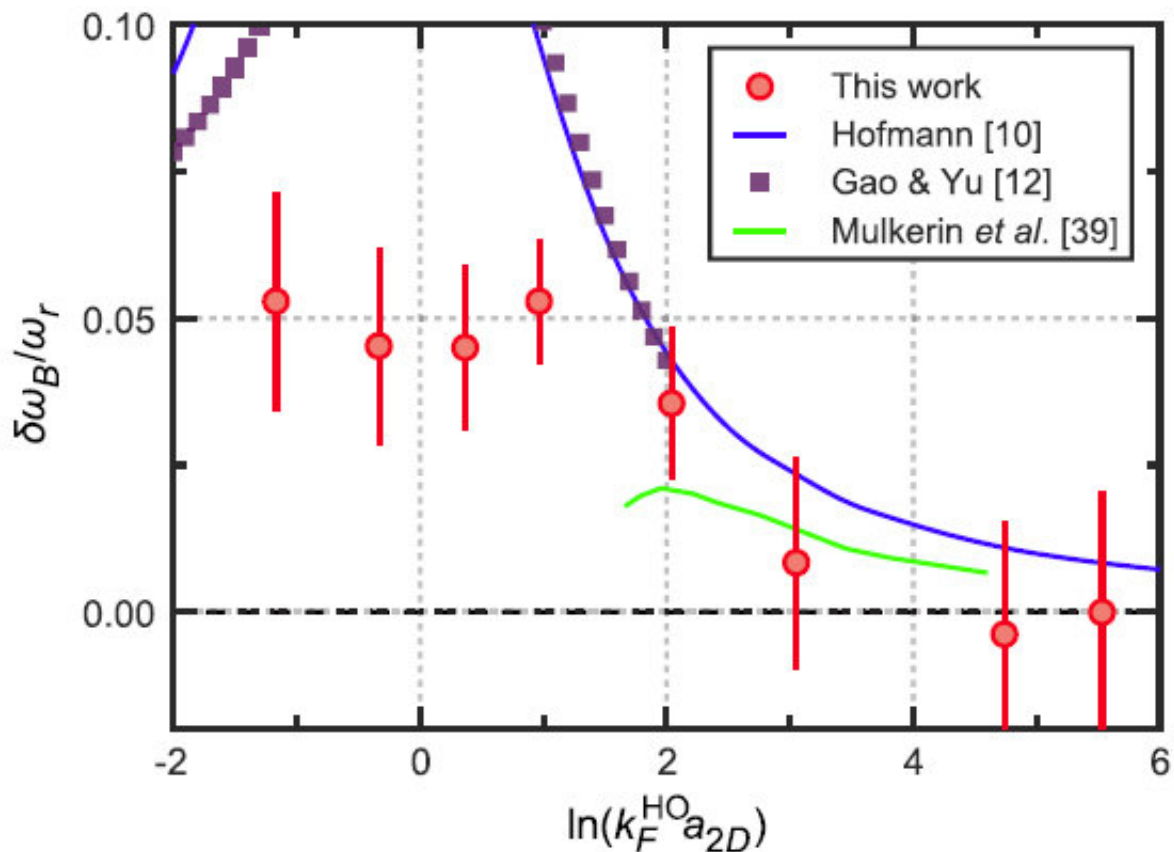


Quantum anomaly—breaking a classical symmetry with ultracold atoms

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Relative shift of breathing mode frequency from the scale-invariant value (black dashed line) as a function of interaction strength Credit: FLEET

A FLEET study of ultracold atomic gases—a billionth the temperature of outer space—has unlocked new, fundamental quantum effects. The

researchers at Swinburne University of Technology studied collective oscillations in ultracold atomic gases, identifying where quantum effects occur to break symmetries predicted by classical physics. They also observed the transition between two-dimensional (2-D) behaviour and three-dimensional (3-D) behaviour.

"Fundamental discoveries made from such observations will inform FLEET's search for electronic conduction without wasted dissipation of energy," explained study-author Professor Chris Vale.

Two-dimensional materials exhibit many novel physical properties and are keenly studied for their potential uses—for example, in ultra-low energy electronics. However, strong correlations and imperfections within 2-D materials make them difficult to understand theoretically. Quantum gases of ultra-cold neutral atoms will help unlock the fundamental physics of 2-D materials, as well as uncovering new phenomena that are not readily accessible in other systems.

Experiments performed on quantum gases of ultra-cold neutral atoms enhance the understanding of phase transitions and the effects of interactions between particles. This improved ability, understanding and control of phase transitions will have a direct application in FLEET's development of future low-energy, topologically-based electronics.

Symmetries are an essential ingredient in the formulation of many physics theories, allowing simplified descriptions by identifying which factors don't modify a system's underlying physical properties. For example, in a scale invariant system, changing the distances between particles doesn't alter the behaviour of a material but merely scales it by an appropriate factor. Gases of [ultracold atoms](#) confined to a two-dimensional plane allowed the researchers to explore regimes where that scaling symmetry can be broken by [quantum effects](#).



A new quantum-gas microscope facility being built at Swinburne University of Technology will allow studies of ultra-cold atomic gases, giving researchers the ability to image and manipulate single atoms. Credit: FLEET

The researchers studied a strongly-interacting 2-D Fermi gas of lithium-6 atoms, measuring the frequency of a radial oscillation known as the breathing mode, the frequency of which is set by the gas compressibility, and is a window to the thermodynamic equation of state. The study confirmed that scaling symmetry is broken in the presence of strong interactions between particles, affecting the thermodynamic relation between the pressure and density. This is called a quantum anomaly, which occurs when a symmetry that is present in a classical theory is broken in the corresponding quantum theory.

Measurements of breathing mode frequency also allowed researchers to map the evolution of thermodynamic equation of state between the 2-D and 3-D limits, showing that strict 2-D behaviour is found in only a very

limited region of parameter space. The study, "Quantum Anomaly and 2-D-3-D Crossover in Strongly Interacting Fermi Gases," was published today in *Physical Review Letters*.

Within FLEET, Chris Vale studies topological phenomena in 2-D gases of ultracold fermionic atoms, investigating cold atom implementations of Floquet topological superfluidity, nonequilibrium enhancements to the superconducting critical temperature and new forms of topological matter based on optically induced spin-orbit coupling in 2-D atomic gases, in Research Theme 3. FLEET's research theme 3 studies systems that are temporarily driven out of thermal equilibrium to investigate the qualitatively different physics displayed and new capabilities for dynamically controlling their behaviour.

Vale leads the study of quantum gases at Swinburne University of Technology. In these collections of atoms cooled to only 100 nanoKelvins above absolute zero, behaviours that are usually only found at the microscopic level become prominent at the macroscopic level. The team's study of Fermi gases confined to 2-D tests new paradigms for dissipationless transport in topological and non-equilibrium quantum matter synthesised from ultracold [atoms](#).

More information: T. Peppler et al, Quantum Anomaly and 2D-3D Crossover in Strongly Interacting Fermi Gases, *Physical Review Letters* (2018). [DOI: 10.1103/PhysRevLett.121.120402](https://doi.org/10.1103/PhysRevLett.121.120402)

Provided by FLEET

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