Ultra-cold lithium atoms shed light on pair formation in superfluids, helping identify best theories

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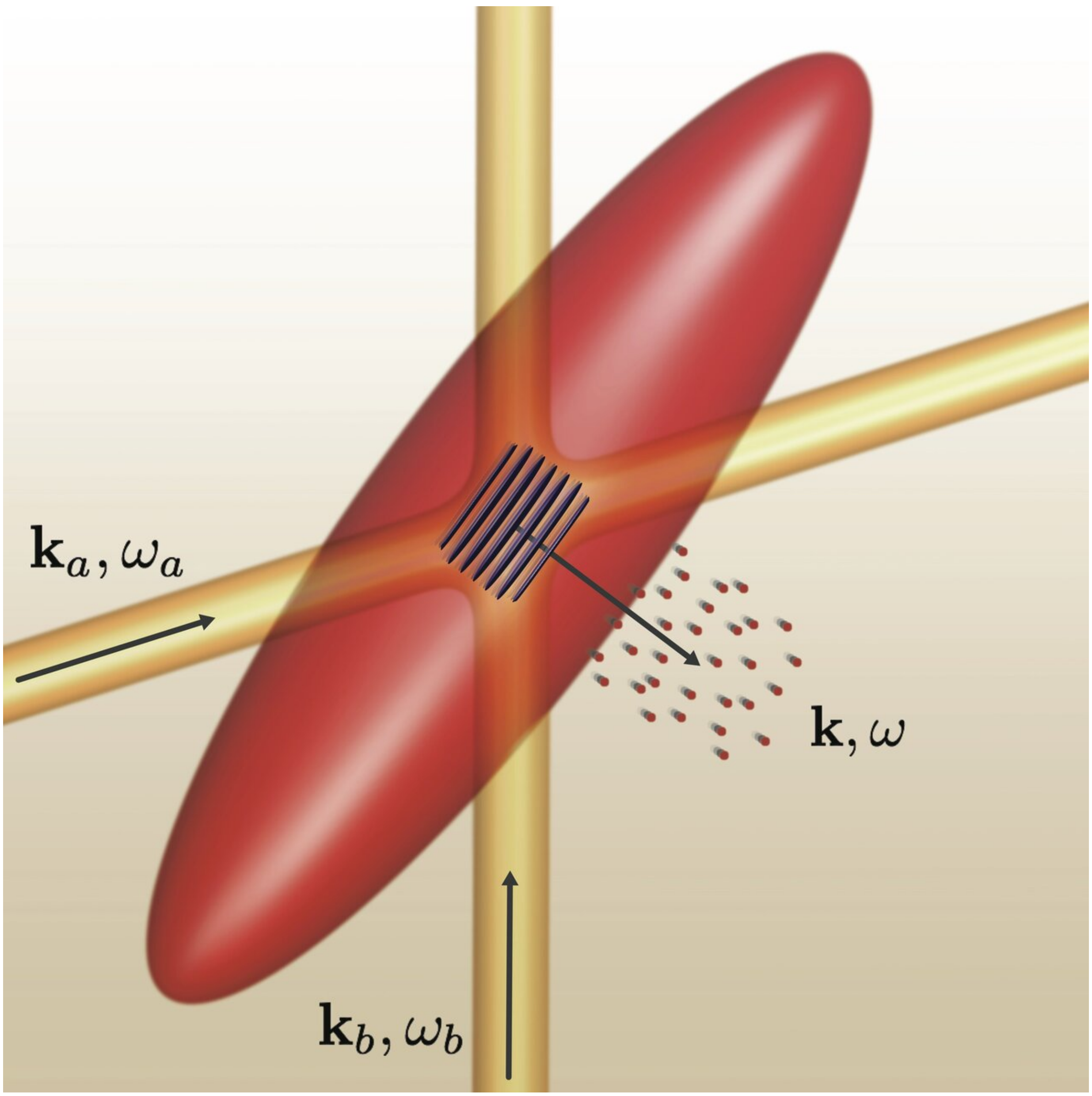

Two laser beams are focused to intersect in the middle of a cloud of lithium atoms, causing some atoms to be scattered out. Credit: FLEET

A FLEET/Swinburne study released this week resolves a long-standing debate about what happens at the microscopic level when matter transitions into a superconducting or superfluid state.

Correlations between pairs of atoms in an ultra-cold gas were found to grow suddenly as the system was cooled below the superfluid transition temperature, rather than appear gradually at higher temperatures, as some theories have predicted.

Experiments were carried out in Swinburne University of Technology's Ultra-cold Atomic Gas laboratory, using gases of lithium atoms cooled to temperatures below 100 nano-Kelvin.

Unlocking pairing mechanism of Fermi-gas systems

The new study unlocks key functions of a state of matter known as a 'Fermi gas', examples of which include electrons moving freely in an electrical conductor (such as in a conventional electric current), or protons and neutrons within a nucleus. Other Fermi gas systems include more-exotic states, such as electrons in superconductors, or the 'superfluid' of neutrons within a neutron star.

"One of the open questions about strongly interacting Fermi-gas systems has been the role of pairing," explains FLEET CI Prof Chris Vale. "Our study demonstrated that, at the superfluid transition temperature, pair-correlations increase abruptly, rather than gradually—as has been predicted by some theories."

This observation was quantified through measurements of a universal parameter, known as the 'contact parameter'. This parameter quantifies the likelihood of finding two atoms in very close proximity to each other, and is strongly enhanced when atoms form pairs.

A related study, by the group of Martin Zwierlein at the Massachusetts Institute of Technology and published back-to-back with the Swinburne group's paper found near identical results, using an entirely different method. The Swinburne and MIT experiments represent a key breakthrough in our understandings of pairing in Fermi superfluid systems with strong interactions between particles.

Experimental results point to correct theory

The Swinburne team generated a unitary Fermi gas of lithium-6 atoms and probed the system by measuring the momentum imparted to the atoms by a pair of crossed laser beams, which perturb the gas in a well-defined manner. From this data, the team extracted the contact parameter, which displayed a rapid increase of around 15% as the temperature was lowered below the superfluid transition point.

Theoretical attempts to calculate the temperature evolution of the contact parameter are notoriously difficult and have yielded very different predictions that depend on the model for interacting fermions. The Swinburne and MIT experiments support the Luttinger-Ward theory, which says that pairing turns on abruptly at the transition temperature.

'Contact and sum-rules in a near-uniform Fermi gas at unitarity' was published in *Physical Review Letters* this week.

More information: C. Carcy et al. Contact and Sum Rules in a Near-Uniform Fermi Gas at Unitarity, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.122.203401 , arxiv.org/abs/1902.07853

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