Physicists prove that 2-D and 3-D liquids are fundamentally different

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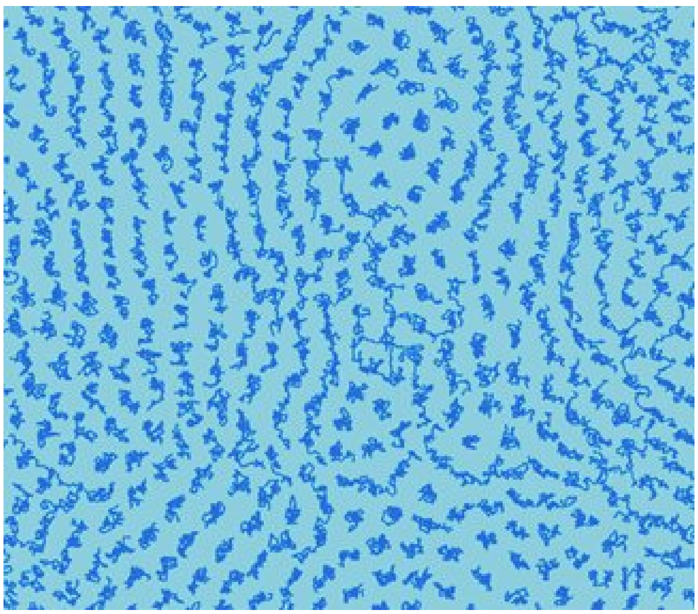

This is an image of atomic trajectories in a two-dimensional liquid, generated by computer simulations. Most trajectories are elongated, and the elongation of close trajectories is similar. This is the visual signature of the collective motions found by Li et al., which demonstrates a fundamental difference between two-dimensional and three-dimensional liquids. Credit: Nanyang Technological University

A 50-year-old puzzle in statistical mechanics has been solved by an international team of researchers who have proved that two-dimensional (2-D) liquids have fundamentally different dynamical properties to three-dimensional (3-D) liquids.

Researchers routinely use 2-D experiments and simulations to represent 3-D liquids, simply because studies in 2-D are easier to do.

With these studies, physicists aim at rationalizing familiar macroscopic fluid properties, such as the viscosity, in terms of the microscopic motion of the particles, which in 2-D can be directly visualized.

The team led by Associate Professor Massimo Pica Ciamarra at Nanyang Technological University, Singapore (NTU Singapore) set out to understand the 'thermal motion' of atoms in 2-D and 3-D liquids.

Using a mix of pen-and-paper calculations and numerical simulations, they predicted that atoms in 2-D liquids can travel for long distances before effectively 'forgetting' their initial positions. This behavior gives rise to a subtle collective motion of the atoms, of a sort that had previously only been thought to occur in solids.

To confirm their theoretical findings, the researchers performed experiments that tracked the motions of colloidal particles under a microscope. In ordinary three-dimensional liquids, such particles execute a type of random motion known as Brownian motion.

But in two-dimensional liquids, the team was able to demonstrate that the Brownian motion is overlaid on large-scale collective motions. This collective motion was previously believed to only occur in 2-D solids, as predicted in the 1960s by Mermin and Wagner.

The proof of the fundamental difference between 2-D and 3-D liquids was obtained by researchers at NTU Singapore, the Jawaharlal Nehru Centre for Advanced Scientific Research in India, the University of Science and Technology of China, and the University of California (Los Angeles) in the United States. Their work was published in November in the *Proceedings of the National Academy of Sciences* (*PNAS*).

"Our discovery shows that two-dimensional liquids and three-dimensional liquids are not just variants of each other, but fundamentally different types of matter," said Assoc Prof Pica Ciamarra.

"Our findings help to explain many puzzling differences between the dynamical properties of two- and three-dimensional liquids, which had been reported in the scientific literature," said Assoc Prof Pica Ciamarra. "It is only in 2-D, not in 3-D or higher dimensions, that the relaxation time is not inversely proportional to the diffusivity of the particles."

"To extract relevant information on the dynamics of 3-D liquids from the 2-D investigations" added Dr. Y.-W. Li, co-author of this study, "researchers need to develop a way to selectively filter-out the effect of the observed collective particle oscillations."

More information: Yan-Wei Li et al. Long-wavelength fluctuations and anomalous dynamics in 2-dimensional liquids, *Proceedings of the National Academy of Sciences* (2019). DOI: 10.1073/pnas.1909319116

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