A way to detect a new quantum phase

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"So many systems in physics look different and do different things," Luming Duan tells *PhysOrg.com*. "But when you get to fundamentals they look very similar. We are looking for new fundamentals that can help us understand different systems."

And that's the key to the latest Letter published by Duan in *Physical Review Letters*. Duan, a professor at the University of Michigan, along with one of his graduate students, Wei Yi, has published a Letter describing a method that could detect an exotic quantum state known as breached-pair phase in an ultracold Fermi gas. Their letter is titled "Detecting the Breached-Pair Phase in a Polarized Ultracold Fermi Gas."

The breached-pair state, a concept first introduced by a Nobel Laureate, Frank Wilczek's group at MIT, is marked by an interesting irregularity: in real space, it is homogenous, polarized superfluid, but in momentum space, there is a definite phase separation. This contrasts with simple mixtures of fermionic atoms and molecular condensates, which experience no phase separation in momentum space. Duan believes that learning to detect breach-pair phase is a step forward in understanding quantum physics and finding new quantum phases to add in further discoveries.

"It's an interesting phase," explains Duan. "It may offer a better understanding of different physical systems, including superconductors under high magnetic fields, exotic quark matter in high energy physics, and superfluid core of neutron stars. These systems may all act differently, but the fundamental quantum physics are pretty similar. We need to learn about these fundamentals, get more information about them."

The breached-pair state is considered a non-BCS superfluid phase, containing fermionic excitations that are gapless. Duan and Yi suggest ultracold atomic gas because it is very controllable, providing an optimal platform to probe such exotic phases. And, while the breached-pair state is still theoretical, Duan has pretty good idea of how it might be detected, and ultimately proved to exist. "We're theorists," he explains, "so we propose methods. And this paper proposes a method to detect breached-pair phase."

Duan and Yi's method involves "measuring the momentum space density profile of the minority spin component." Since breached-pair phase appears different from other phases in momentum space, this is a feasible method. "If one measures the momentum space density profiles," asserts Duan and Yi in their Letter, "the profile for the minority atoms should be nonmonotonic with the dip in momentum distribution." This offers a clear signature for a breached-pair phase — a signature no other quantum phase has. Additionally, Duan and Yi insist, it would be possible to differentiate between different *kinds* of breached-pair states.

"Breach-pair phase is different," says Duan. "Instead of phase separation in real space, you have paired and unpaired atoms in different regions of momentum space. This kind of phase will be observed in the near future."

While the existence of a breached-pair state has yet to be proved, Duan is confident that it could be detected experimentally. While it would not be particularly easy to set up such an experiment, it is possible. Duan asserts, "It is possible to test our method within the current technology. It is feasible for experimental efforts."

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