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► *By Martin Zwierlein*

ESI Special Topics, June 2006

Citing URL - <http://www.esi-topics.com/fbp/2006/june06-MartinZwierlein.html>



Martin Zwierlein answers a few questions about this month's fast breaking paper in the field of Physics. The author has also sent along images of their work.

From •>>June 2006

Field: Physics

Article Title: Vortices and superfluidity in a strongly interacting Fermi gas

Authors: **Zwierlein, MW**; Abo-Shaer, JR; Schirotzek, A; Schunck, CH; [Ketterle, W](#)

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ST: Why do you think your paper is highly cited?

The paper presents the first direct observation of [superfluidity](#) in a gas of fermionic atoms, which has been a major goal in ultracold atom research. Ultracold atomic gases, a million times thinner than air, offer the remarkable possibility to study the phenomenon of superfluidity in a very clean and highly controllable way. So far, this had been achieved only for gases of bosons, particles with integer spin.

In this work we demonstrate superfluidity in a gas of fermions, particles with half-integer spin: after setting the gas in rotation, a regular array of vortices (mini-tornadoes) is observed.

[Click](#) to see full image.

To become superfluid, fermions have to team up and form pairs. These pairs are bosons and can thus "march in lockstep," forming one big quantum-mechanical matter wave.

Fermionic pairing and superfluidity are central to many diverse fields of physics, as fermions (such as protons, neutrons, and electrons) are the building blocks of matter. For example, the phenomenon is closely connected to superconductivity of electrons in a metal, where electron pairs flow without any resistance or loss. As such, our work is of immediate interest not only to atomic physicists, but also to researchers in the fields of condensed matter physics, nuclear physics, and astronomy.



"Demonstrating fermionic superfluidity had been a long-standing goal in experiments with cold fermions."

ST: Does it describe a new discovery, methodology, or synthesis of knowledge?

It describes the discovery of high-temperature superfluidity in a strongly interacting Fermi gas. This also presents a synthesis of knowledge, as several experiments over the past years had already uncovered pieces of the puzzle (in six laboratories around the world: JILA (Boulder), Duke, Paris, Rice, Innsbruck, and MIT).

It was known before that the gas was strongly interacting, that it consisted of pairs of fermions, and that these pairs could condense into a very low-energy state. Our observation of vortices in the rotating gas provided the "smoking gun" that this gas was actually a superfluid.

ST: Could you summarize the significance of your paper in layman's terms?

A superfluid gas can flow without resistance. It can be clearly distinguished from a normal gas when it is rotated. A normal gas rotates like an ordinary object, but a superfluid can only rotate when it forms vortices similar to mini-tornadoes. This gives a rotating superfluid the appearance of Swiss cheese, where the holes are the cores of the mini-tornadoes.

Demonstrating fermionic superfluidity had been a long-standing goal in experiments with cold fermions. Our fermion of choice was the lithium-6 isotope comprising three protons, three neutrons, and three electrons. Since the total number of constituents is odd, lithium-6 is a fermion.

Using laser and evaporative cooling techniques, we cooled the gas close to absolute zero. Next, the gas was trapped in the focus of an infrared laser beam; the electric and magnetic fields of the infrared light held the atoms in place.

The last step was to spin a green laser beam around the gas to set it into rotation. This was just like using a spoon to stir up the coffee in your mug and making the liquid spin around. A shadow picture of the cloud showed its superfluid behavior: the cloud was pierced by a regular array of vortices, each about the same size.

We were able to view these superfluid vortices at extremely cold temperatures, when the fermionic gas was cooled to about 50 billionths of a degree Kelvin, very close to absolute zero (-273 degrees C or -459 degrees F). Although "ultracold" in absolute terms, this temperature is actually quite "high" when compared with the energy content of the gas (which is very small due to its ultra-low density). In this sense, the temperature of the ultra-dilute superfluid observed by our group exceeds by far the transition temperature for high-temperature superconductors. Scaled to the density of electrons in a metal, the superfluid transition would occur far above room temperature.

This is fascinating, as even the remote possibility of making a room-temperature superconductor spurs hopes that we will one day transport electricity without any loss.

ST: How did you become involved in this research, and were any problems encountered along the way?

This work was done during my Ph.D. studies in Wolfgang Ketterle's group at MIT. The team members on this project were former graduate student Jamil Abo-Shaeer (now at Lawrence Berkeley National Laboratory), and graduate students André Schirotzek and Christian Schunck.


Our approach in cooling fermions was to use a "refrigerator"—a cloud of sodium atoms. This part of the apparatus produced the first Bose-Einstein condensates of sodium atoms in 1995. In 2001 the machine was upgraded to a double-species experiment which could cool fermionic lithium-6 by thermal contact with sodium.

In 2003/2004, [Bose-Einstein condensation](#) of pairs of lithium-6 atoms was observed (related [link](#)).

To show that the gas was indeed a superfluid, we had to develop a technique to set it in rotation, which required a very round container. This presented a major difficulty, as our container was an optical trap—a focused laser beam—combined with strong magnetic fields. It was necessary to literally "sand off the bumps" of our trap to make it perfectly round.

ST: Are there any social or political implications for your research?

The US is currently losing more than 10% of their entire energy production in the sheer transport of electricity from one place to another. This lost amount of energy would be enough to power entire countries. Clearly we would benefit from replacing normal wires by superconducting ones that transport current without any loss.

However, this is only realistic if we find materials that have a high transition temperature at which they become superconducting. The high-temperature superfluid Fermi gas created at MIT can serve as an easily controllable model system to study properties of superconductors. This will undoubtedly improve our understanding of the limits and prospects of superconductivity at high temperature. 

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Read past comments by co-author Wolfgang Ketterle;

- [Science Watch® interview](#)
- [Fast Breaking Paper comment](#)
- [Interview](#) for the special topic of [Bose-Einstein condensates](#)

A Closer Look...



Below are images sent in by Martin Zwierlein which correspond with the featured paper, or current research.

Figure 1:

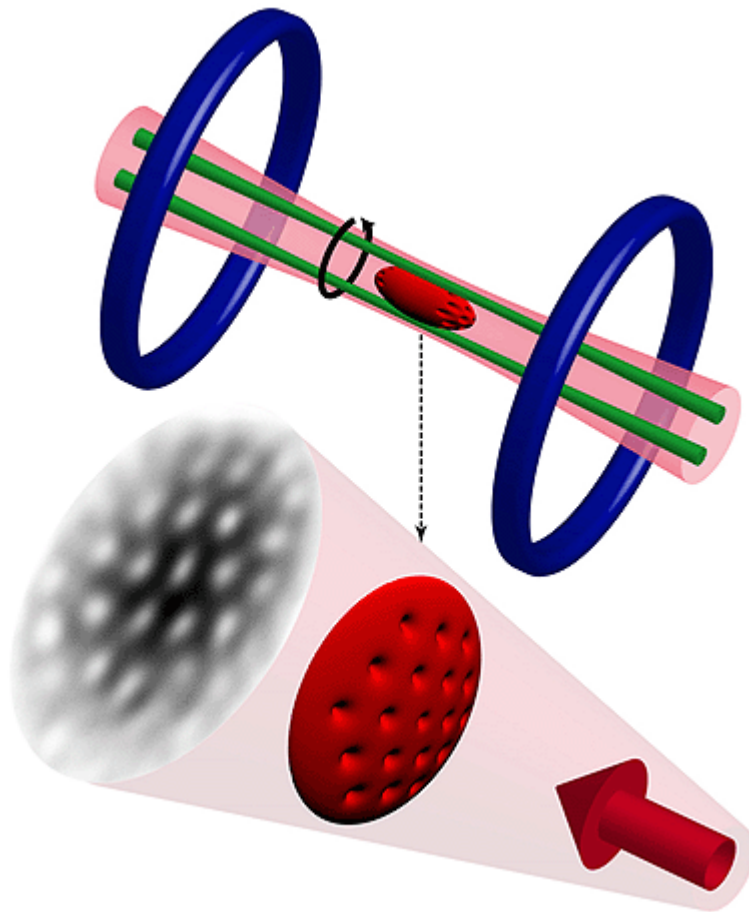
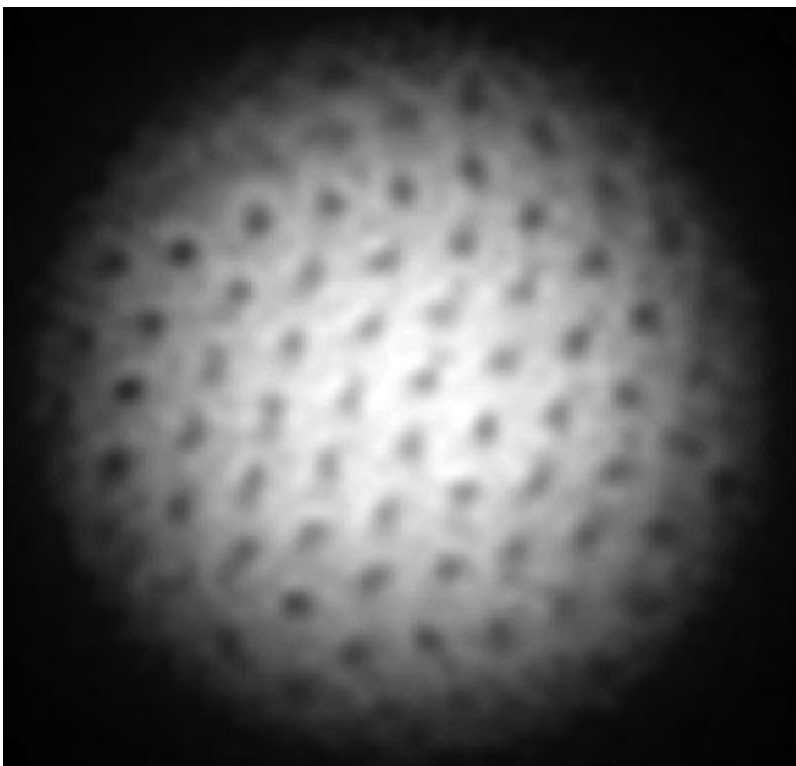


Figure 1 description:

Experimental Setup. The ultracold Fermi gas is held in the focus of a laser beam (pink) and in the magnetic field created by two coils (blue). Two additional laser beams (green) set the cloud in rotation. An absorption image of the expanded gas (below) reveals the vortex lattice.

Figure 2:

Figure 2

**description:**

Absorption image of the vortex lattice in a strongly interacting Fermi gas.

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