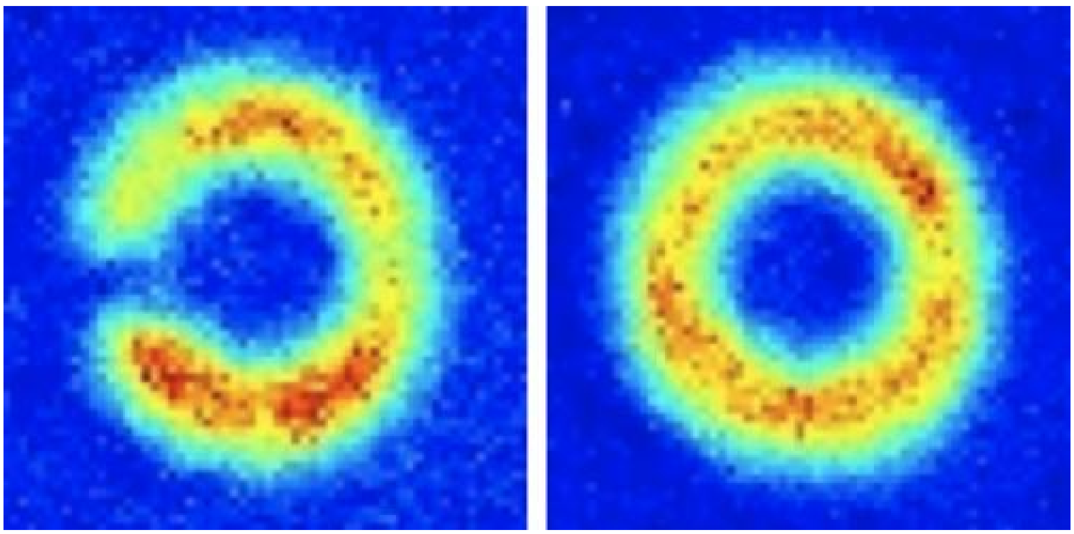
The first non-trivial atom circuit: Progress towards an atom SQUID

March 31 2011



Atom circuit: False color images of an "atom circuit" made of an ultracold sodium gas. Red denotes a greater density of atoms and traces the path of circulating atoms around the ring. A laser-based barrier can stop the flow of atoms around the circuit (left); without the barrier the atoms circulate around the ring (right). Credit: JQI/NIST

(PhysOrg.com) -- Researchers from the National Institute of Standards and Technology and the University of Maryland have created the first nontrivial "atom circuit," a donut-shaped loop of ultracold gas atoms circulating in a current analogous to a ring of electrons in a superconducting wire. The circuit is "nontrivial" because it includes a circuit element—an adjustable barrier that controls the flow of atom current to specific allowed values. The newly published work was done at the Joint Quantum Institute, a NIST/UM collaboration.

Ultracold gases, such as the Bose-Einstein condensate of sodium atoms in this experiment, are fluids that exhibit the unusual rules of the quantum world. Atomic quantum fluids show promise for constructing ultraprecise versions of sensors and other devices such as gyroscopes (which stabilize objects and aid in navigation). Super?uid helium circuits have already been used to detect rotation. Superconducting quantum interference devices (SQUIDs) use superconducting electrons in a loop to make highly sensitive measurements of magnetic fields. Researchers are striving to create an ultracold-gas version of a SQUID, which could detect rotation. Combined with ultracold atomic-gas analogs of other electronic devices and circuits, or "atomtronics" that have been envisioned, such as diodes and transistors, this work could set the stage for a new generation of ultracold-gas-based precision sensors.

To make their atom circuit, researchers created a long-lived persistent current—a frictionless flow of particles—in a Bose-Einstein condensate of sodium atoms held by an arrangement of lasers in a so-called optical trap that confines them to a toroidal, or donut, shape. Persistent flow—occurring for a record-high 40 seconds in this experiment—is a hallmark of superfluidity, the fluid analog of superconductivity.

The atom current does not circle the ring at just any velocity, but only at specified values, corresponding in this experiment to just a single quantum of angular momentum. A focused laser beam creates the circuit element—a barrier across one side of the ring. The barrier constitutes a tunable "weak link" that can turn off the current around the loop.

Superflow stops abruptly when the strength of the barrier is sufficiently high. Like water in a pinched garden hose, the atoms speed up in the vicinity of the barrier. But when the velocity reaches a critical value, the atoms encounter resistance to flow (viscosity) and the circulation stops, as there are no external forces to sustain it.

In atomic Bose-Einstein condensates, researchers have previously created Josephson junctions, a thin barrier separating two superfluid regions, in a single atomic trap. SQUIDs require a Josephson junction in a circuit. This present work represents the implementation of a complete atom circuit, containing a superfluid ring of current and a tunable weak link barrier. This is an important step toward realizing an atomic SQUID analog.

More information: A. Ramanathan, K. C. Wright, S. R. Muniz, M. Zelan, W. T. Hill III, C. J. Lobb, K. Helmerson, W. D. Phillips and G. K. Campbell. Superflow in a toroidal Bose-Einstein condensate: an atom circuit with a tunable weak link. *Physical Review Letters.* Published online March 28, 2011.

Provided by National Institute of Standards and Technology