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much more stable than water at its boiling point.

The possibility of stable liquid water over large parts of the Martian surface may help to explain certain features—gullies and rocky outcrops—that show signs of having been formed from sedimentation or erosion by water.² (See the article by Bruce Jakosky and Michael Mellon in *PHYSICS TODAY*, April 2004, page 71.) Some gullies seem to

have formed in the past few million years. Says Phillips, “This certainly changes the way we interpret observations of Mars’s current climate and possibly current water-driven surface processes.”

Johanna Miller

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Clouds of atoms with opposite spins bounce off one another

A gas of strongly interacting ultracold atoms offers extremely high resistance to the flow of spin; its spin diffusion reaches a minimum, universal value.

The transport properties of ultracold gases can provide insight into many-body systems that are less tractable experimentally, such as quark-gluon plasmas or high-temperature superconductors. Many such systems are subjects of a recent interest in perfect fluids (see the special issue of *PHYSICS TODAY*, May 2010).

Thus, when MIT researchers led by Martin Zwierlein recently learned to spatially separate the spin-up and spin-down components of a trapped gas of strongly interacting Fermi atoms, they explored the transport of spins by sending two atomic clouds of opposite spin traveling toward one another. It was not clear what the outcome would be. Perhaps the atoms of opposite spin would pair up, forming a superfluid. Or maybe the spins would remain separate, with the high collision rate of the strongly interacting atoms greatly slowing the time for the two clouds to merge.

The researchers observed far more dramatic and unexpected behavior.¹ The atom clouds, which are a million times thinner than air, ricocheted as if they were billiard balls. As lead author Ariel Sommer puts it, “When we saw these ultradilute puffs of gas bounce off one another, we were completely amazed.”

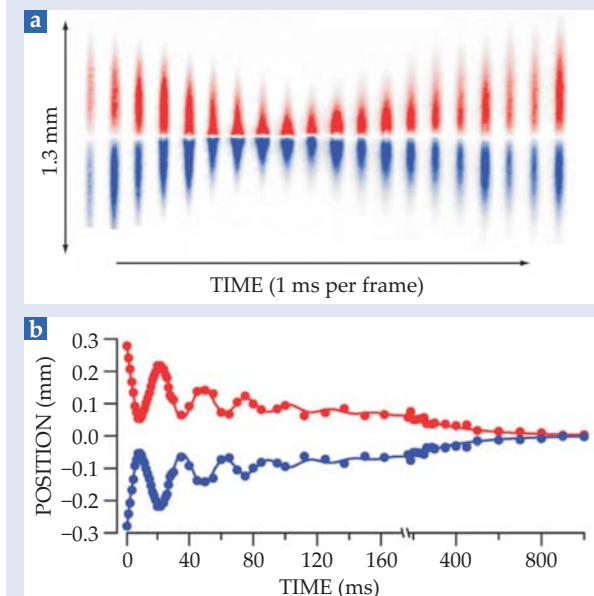
The atom clouds were moving in a harmonic potential applied along the axis of a cylindrical trap, much like two balls rolling down opposite sides of a U-shaped track. At the bottom they repelled, then traveled partway back up the sides of the track, and returned for subsequent bounces until the motion was damped and the clouds began to merge. The sharp demarcation between the clouds during the first bounce is seen in the top panel of the figure. It

took nearly a second for the spins in the merged clouds to be homogeneously distributed, as illustrated in the figure’s bottom panel.

For their experiment, the MIT researchers confined a gas of fermionic lithium-6 atoms in a cylindrically symmetric optical trap. The trap also used a magnetic field for confinement in the axial direction. The gas contained an equal mixture of the two lowest hyperfine states, which can be considered the up and down components of a two-state spin system. The researchers cooled the gas to temperatures near the Fermi temperature T_F , below which the gas is degenerate, with atoms filling most of the lowest energy states.

Zwierlein and his team separated the two spin states by first setting the magnetic field to a value where the spin components had unequal magnetic moments and applying a magnetic field gradient along the cylindrical trap. Once the atom clouds were pulled apart, the experimenters raised the field to equalize the spin magnetic moments. Because of the axial harmonic confinement, the atom clouds were attracted to the center of the trap. By tuning the value of the magnetic field, Zwierlein and his team could control the strength of interaction between atoms, setting it at the Feshbach resonance, where the interaction is strongest. (See the discussion by Daniel Kleppner, *PHYSICS TODAY*, August 2004, page 12.)

At the Feshbach resonance, the strong scattering between atoms of opposite spin in a moderately degenerate Fermi gas gives the shortest possible mean free path, equal to the interparticle spacing. Even though atoms with opposite spins can attract and form pairs, in this instance they repel. Sommer likens the repulsion or attraction to



The repulsion between clouds of atoms with oppositely oriented spins causes the clouds to bounce off one another. **(a)** A map of the excess density of spin-up (red) or spin-down (blue) atoms in each cloud during the first bounce. Images of the clouds were taken in 1-ms intervals. The axis of the cylindrically symmetric trap lies along the vertical direction in the image. **(b)** The centers of mass of the two spin clouds oscillate until the bouncing motion is

damped. It takes about one second for the two clouds to diffuse into one another. (Adapted from ref. 1.)

dips or bumps in the path of a rolling ball: Either type will deflect the ball from a straight path. When the spin-up atoms first encounter the spin-down atoms, some may be scattered backward, where they meet no resistance because the Pauli exclusion principle forbids any interaction between atoms with the same spin. Such backward scattering events lead to the observed bounces.

At the Feshbach resonance, the system is expected to exhibit universal properties that are the same for all non-relativistic, dilute gases of fermions—be they atoms, electrons, or quarks— independent of the shape of the interaction potential. In that universal regime, the energy and length scales are set by the Fermi energy E_F and interparticle spacing, and the equilibrium properties depend only on the scaled temperature T/T_F .

In this universal regime, the MIT team measured the spin drag, or resistance to spin flow, and the spin diffusivity, which controls how long it takes for the spin densities to even out. The spin drag coefficient reached a maximum value of $0.1 E_F/\hbar$, which depends only on particle mass m and the gas density. The spin diffusivity approached a quantum limit given by $\hbar/m$. The universal dependence allows researchers to map the results onto the behavior of a much denser collection of particles having a very different mass, such as the neutrons in a neutron star.

John Thomas of Duke University,

with colleagues from Duke, Gustavus Adolphus College, and North Carolina State University, has recently studied momentum transport in a strongly interacting Fermi gas and found that the shear viscosity is extremely low.² At first glance, comments Thomas,³ it seems counterintuitive for a gas to manifest strong spin drag and at the same time a low shear viscosity. However, the two phenomena stem from the same strong interactions between atoms of opposite spin. To understand the low shear viscosity, consider dragging a sheet through the gas. The momentum imparted by it to the nearby atoms gets quickly equilibrated through collisions, and atoms further away no longer feel the presence of the sheet.

The MIT results have important implications for studies of dynamics in other systems, in which it is often critical to know how fast a system might reach equilibrium, remarks David Huse of Princeton University. Such studies are easier in an ultracold gas than in a condensed-matter system, where the time scales are much shorter.

Barbara Goss Levi

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