FERMIONIC SUPERFLUIDITY AND THE BEC-BCS CROSSOVER IN ULTRACOLD ATOMIC FERMI GASES

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In our recent experiments at MIT, superfluidity has been observed in a strongly interacting atomic Fermi gas. These systems constitute a novel form of matter with model character: One can vary the temperature, density and dimensionality, the number of "spin up" versus "spin down" fermions, and, most remarkably, the interactions can be precisely controlled over an enormous range. This allows to study the crossover of a Bose-Einstein condensate of tightly bound molecules to a Bardeen-Cooper-Schrieffer superfluid of long-range Cooper pairs.

Superfluidity in this crossover regime is demonstrated by setting the gas under rotation and observing ordered lattices of quantized vortices [1]. Thanks to its strong interactions, the gas is a high-temperature superfluid: Scaled to the density of electrons in a metal, superfluidity would occur already far above room temperature.

A new regime is entered when the number of spin up versus spin down atoms is imbalanced. In this case, not every spin up atom can find a spin down partner. The ground state of such a system has been under debate for over 40 years. We observe the breakdown of superfluidity at a critical imbalance, the Chandrasekhar-Clogston limit [2]. The superfluid gives way to an intriguing, strongly-interacting Fermi gas with unequal spin populations [3, 4].

Bosonic vs Fermionic Superfluids

It is a remarkable fact of history that the first fermionic superfluid was created using a bosonic one as the coolant. In 1908, Heike Kamerlingh-Onnes liquefied helium. In these experiments, he already reached the critical temperature for superfluidity of helium at 2.2 K, the onset of frictionless flow, although these and other remarkable properties of superfluids remained unnoticed at the time. He moved on to use helium to cool down mercury. In 1911 he observed that at the critical temperature of 4.2 K the resistance of the metal dropped suddenly to non-measurable values, it became "superconducting". Tin (at 3.8 K) and lead (at 6 K) showed the same remarkable phenomenon. This was the discovery of superfluidity in an electron gas.

The fact that bosonic superfluidity and fermionic superfluidity were first observed at very similar temperatures, is due to purely technical reasons (because of the available cryogenic methods) and rather obscures the very different physics behind these two phenomena.

Bosonic superfluidity occurs via Bose-Einstein condensation at the degeneracy temperature, i.e. the temperature T at which the spacing between particles $n^{-1/3}$ at density n becomes comparable to the thermal de Broglie wavelength $\lambda = h/mv_{\mathrm{th}}$, where m is the particle mass and $v_{\mathrm{th}} \sim (k_B T/m)^{1/2}$ is the thermal velocity. The predicted transition temperature of $T_{\mathrm{BEC}} \sim h^2 \, n^{2/3}/m \approx 3$ K for liquid helium at a typical density of $n = 10^{22}$ cm^{-3} coincides with the observed lambda point.

In contrast, the degeneracy temperature (equal to the Fermi temperature $T_F = E_F/k_B$) for conduction electrons is higher by the mass ratio $m_{4\mathrm{He}}/m_e$, bringing it up to several ten-thousand degrees. It was only in 1957 when it became clear why in fermionic systems, superfluidity occurs only at temperatures much smaller than the degeneracy temperature.

Of course, the main difference to Bose gases is that electrons, being fermions, cannot be in one and the same quantum state but instead must arrange themselves in *different* states. An obvious scenario for superfluidity might be the formation of tightly bound pairs of electrons that can act as bosons and could form a condensate. But apart from the problem that the condensation temperature would still be on the order of E_F/k_B, there is no known interaction which could be sufficient to overcome the strong Coulomb repulsion and form tightly bound electron pairs. The idea itself of electrons forming pairs was indeed correct, but the conceptual difficulties were so profound that it took several decades from the discovery of superconductivity to the correct physical theory.

In 1950, it became clear that there was indeed an effective attractive interaction between electrons, mediated by the crystal lattice vibrations (phonons), that was responsible for superconductivity. The lattice vibrations left their mark in the characteristic variation of the critical temperature with the isotope mass of the crystal ions, the isotope effect. But the scale of the lattice vibrations, the Deby-temperature T_D, was still too large to explain the observed low critical temperatures for superconductivity.

A breakthrough came in 1956, when L. Cooper realized that fermions interacting via an arbitrarily weak attractive interaction on top of a filled Fermi sea can form a bound pair. In other words, the Fermi sea is unstable towards pair formation.

However, unlike the tightly bound pairs considered before, the "Cooper"-pair is very large, much larger than the interparticle spacing. That is, a collection of these pairs necessarily needs to overlap very strongly in space. In this situation, it was far from obvious whether interactions between different pairs could simply be neglected. But it was this simplifying idea that led to the final goal: Bardeen, Cooper and Schrieffer (BCS) developed a full theory of superconductivity starting from a new, stable ground state in which pair formation was included in a self-consistent way. The pair binding energy was found to be exponentially suppressed compared to the Debye energy-scale, $T_C \sim T_D\, exp(-1/\rho(E_F)V)$, with $\rho(E_F)$ the density of states at the Fermi energy and V the effective phonon-mediated electron-electron interaction. Hence, the critical temperature is proportional to the Debye-temperature, in accord with the isotope effect, but the fragile nature of Cooper pairing suppresses T_C by an exponentially small factor.

The BEC-BCS Crossover

It appears that there are vastly different scenarios for bosonic and fermionic superfluidity. Bose-Einstein Condensation of point-like bosons and Condensation of long-range Cooper pairs, often depicted as pairing in momentum space. On the other hand, a ^{4}He atom can be viewed as a tightly bound fermion pair, consisting of a fermionic ion bound to an electron. From the BCS viewpoint, one can ask what will happen when Cooper pairs are more and more strongly bound as the interactions or the density are increased.

It was Popov, Keldysh and Eagles who realized in different contexts that the BCS formalism and its Ansatz for the ground state wavefunction provides not only a good

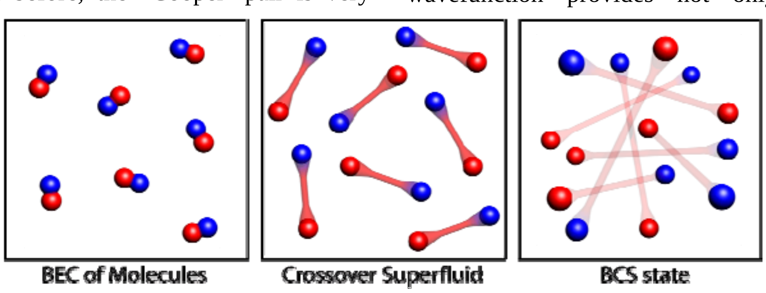

Fig. 1 The BEC-BCS crossover in a mixture of spin up (red) and spin down atoms (blue) connects the limit of a Bose-Einstein condensate of tightly bound molecules (left) to the limit of a Barden-Cooper-Schrieffer superfluid of long-range Cooper pairs (right). In between, one deals with a strongly interacting "soup" of pairs whose pairsize is on the order of the interparticle distance.

description for a condensate of Cooper pairs, but also for a Bose-Einstein condensate of tightly bound pairs. Leggett showed in 1980 in a beautifully simple model that the two limits of fermionic superfluidity, tightly bound molecules and long-range Cooper pairs, are connected in a smooth crossover. Nozières and Schmitt-Rink extended Leggett's model to the normal state at finite temperatures and verified that the critical temperature for superfluidity varies smoothly from the BCS limit, where it is exponentially small, to the BEC limit where one recovers the value for the Bose-Einstein condensation of tightly bound molecules (see Fig. 3).

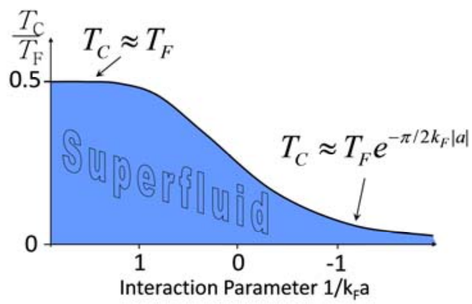

Fig. 2 Sketch of the critical temperature in the BEC-BCS crossover as a function of the interaction parameter $1/k_F a$.

The interest in strongly interacting fermions and the BCS-BEC crossover increased with the discovery of high-temperature superconductors in 1986 by Bednorz and Müller. The physics of the BEC-BCS crossover in a gas of interacting fermions does not directly relate to the complicated phenomena observed in High-T_C materials. However, the two problems share several features: A pair size (or correlation length) comparable to the interparticle distance and a normal state above T_C which is far from being an ordinary Fermi gas. In the normal state, correlations are still strong enough to form uncondensed pairs at finite momentum.In High-T_C materials, this region in the phase diagram is referred to as the "Nernst regime", part of a larger region called the "Pseudo-gap".

The Unitarity Limit

One point in the BEC-BCS crossover is of special interest: When the interparticle potential is just about strong enough to bind two particles in free space, the bond length of this molecule tends to infinity (unitarity regime). In the medium, this bond length will not play any role anymore in the description of the many-body state. The only length scale of importance is then the interparticle distance $n^{-1/3}$, the corresponding energy scale is the Fermi energy E_F. In this case, physics is said to be universal. The average energy content of the gas, the binding energy of a pair, and (k_B times) the critical temperature must be related to the Fermi energy by universal numerical constants. The size of a fermion pair must be given by a universal constant times the interparticle distance.

It is at the unitarity point that fermionic interactions are at their strongest. Further increase of attractive interactions will lead to the appearance of a bound state and turn fermion pairs into bosons. As a result, the highest transition temperatures for fermionic superfluidity are obtained around unitarity and are on the order of the degeneracy temperature. Finally, almost 100 years after Kamerlingh Onnes, it is not just an accidental coincidence anymore that bosonic and fermionic superfluidity occur at similar temperatures!

High-Temperature Superfluidity

The crossover condensates realized in the experiments on ultracold Fermi gases are a new type of fermionic superfluid. This superfluid differs from ^{3}He, conventional and even High-T_C superconductors in its high critical temperature T_C when compared to the Fermi temperature T_F. Indeed, while T_C/T_F is about $10^{-5}\ldots10^{-4}$ for conventional superconductors, 5×10^{-4} for ^{3}He and 10^{-2} for High-T_C superconductors, the strong interactions induced by the Feshbach resonance allow atomic Fermi gases to enter the superfluid state already at $T_C/T_F \approx 0.2$, as summarized in Table 1. It is this large value which allows us to call this phenomenon "*high-temperature superfluidity*". Scaled to the density of electrons in a metal, this form of superfluidity would already occur far above room temperature (actually, even above the melting temperature).

System	T_C	T_F	T_C/T_F
Metallic Super-conductors (typ.)	1-10 K	50000 – 150000 K	10^{-4} – 10^{-5}
^{3}He	2.6 mK	5 K	$5 \cdot 10^{-4}$
High-T_C Super-conductors	35-140 K	2000 – 5000 K	$(1-5)\cdot 10^{-2}$
Neutron stars	10^{10} K	10^{11} K	10^{-1}
Stronlgly interacting Fermi Gases	200 nK	1 μK	0.2

Table 1 Transition temperatures, Fermi temperatures and their ratio T_C/T_F for a variety of fermionic superfluids or superconductors.

Realization in ultracold atomic Fermi gases

After the accomplishment of quantum degeneracy in bosons in 1995, one important goal was the study of quantum degenerate fermions. A difficulty in cooling fermions arises directly from the Pauli exclusion principle. In evaporative cooling, the technique that allowed reaching the degeneracy temperature in bosons, the most energetic atoms are forced to escape from the trap, while the rest of the sample rethermalizes at a lower temperature. However, spin-polarized fermions can no longer thermalize at temperatures below the threshold for p-wave collisions, as s-wave (head-on) collisions are forbidden by the Pauli principle. Experiments on ultracold fermions thus have to employ a mixture of either two hyperfine states of the same atom or a second species of atoms to guarantee thermalization. The first degenerate Fermi gas was created by B. DeMarco and D. Jin in 1999 at JILA using a spin-mixture of fermionic ^{40}K [5].

Until the end of 2003, six more groups had succeeded in producing ultracold degenerate Fermi gases, one more using ^{40}K [6], and five using ^{6}Li [7-11]. Between 1999 and 2001, the ideal Fermi gas and its collisional properties were studied.

At first sight, the prospects for reaching superfluidity in these alkali Fermi gases seemed dim. The van-der-Waals interactions in these gases are typically weak, resulting in a very low binding energy of Cooper pairs and thus a critical temperature for superfluidity far too low to be achievable in experiments. Interactions at low temperatures are mediated exclusively via s-wave collisions between unlike spins. They are characterized by the scattering length a, which is typically in the range of the van der Waals-length, about 100 a_0. This is much smaller than the interparticle distance $\sim 1/k_F \sim 3000\, a_0$ between particles. The ratio $1/k_F a$ is a measure for the interaction strength. The critical temperature for BCS-type s-wave superfluidity is given by

$$T_C \approx E_F \exp(-\pi/2k_F a)$$

It scales as the Fermi energy, essentially the degeneracy temperature, which experimenters knew how to reach since 1995. However, it is suppressed with respect to that energy scale by a factor that depends exponentially on the interaction strength. This factor is easily 10^{-20}.

However, the ^{6}Li atom was early on thought to be a good candidate for a fermionic superfluid due to its large and negative (triplet) scattering length $a \sim -2000\, a_0$. This spurred hope that one might be able to actually reach T_C in experiments. In addition, already from work with Bose-Einstein condensates, it was known that the scattering length can be tuned near a so-called Feshbach resonance.

In a Feshbach resonance, a bound state of the intermolecular potential (say, a singlet with total spin S=0) is tuned in resonance with the energy of two colliding atoms (colliding, say as a triplet, S=1) (see Fig. 3). Due to the different Zeeman shifts of molecular state (essentially zero magnetic moment) and the triplet state (magnetic moment typically $2\mu_B$), this tuning can be achieved by simply applying a bias magnetic field. For the field where the free-atom and the molecular states cross, a scattering resonance occurs. One one side of the resonance, atom pairs can form stable molecules, while on the other side, atom pairs are, at least in free space, unstable. Only the presence of a surrounding Fermi sea can stabilize fermion pairs in this regime ("BCS-side" of the Feshbach resonance). Diatomic molecules can be formed by either adiabatically sweeping the magnetic field from the "free atom" to the "molecular" side or by three-body collisions of free atoms directly on the molecular side.

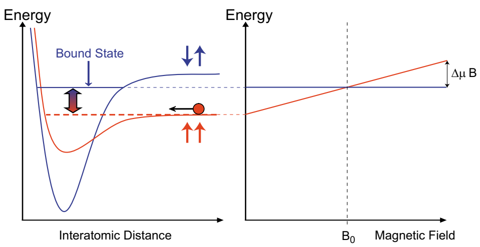

Fig. 3 Origin of Feshbach resonances. Atoms entering f. ex. in the triplet potential are coupled to a singlet bound molecular state. By tuning the external magnetic field, this bound state can be brought into resonance with the incoming state (at B_0 in the graph on the right).

In bosons, the resonant enhancement of the elastic collision rate is unfortunately accompanied by resonantly enhanced three-body losses. The hope for achieving superfluidity in Fermi gases truly intensified in the year 2003, when C. Salomon's group at the ENS in Paris found that *fermionic atoms*, in contrast to their bosonic counterparts, are extremely stable close to such a Feshbach resonance. It thus became clear that one could directly cool the Fermi mixture at a Feshbach resonance, induce strong interactions so that rather small and stable fermion pairs (Feshbach molecules) would form, which should then condense. The race was on to form the first Bose-Einstein condensate of molecules.

In November 2003, three groups reported the realization of Bose-Einstein condensates of molecules (see Fig. 4). In fact, these experiments already realized crossover condensates. They operated in the strongly interacting regime with $k_F a > 1$, where the size of the pairs is not small with respect to the interparticle spacing. When the interparticle spacing $\sim 1/k_F$ becomes smaller than the scattering length $\sim a$, the two-body molecular state is not relevant anymore and pairing is a many-body affair. Soon after these first experiments on fermion pair condensates, their observation was extended throughout the whole BEC-BCS crossover region by employing a rapid ramp to the "BEC"-side of the Feshbach resonance [12][13].

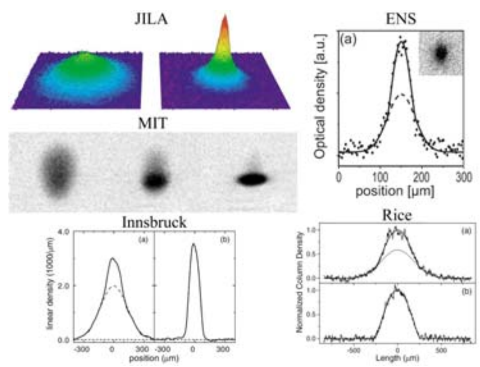

Fig. 4 Observation of Bose-Einstein condensation of molecules. The gallery shows bimodal density distributions observed after expansion and molecule dissociation at JILA, after expansion, dissociation and zero-field imaging at MIT [14] and at the ENS [15], and in-situ profiles from Innsbruck [16] and Rice [17].

In the following years, properties of this new crossover superfluid were studied in thermodynamic measurements, collective excitations, and radiofrequency spectroscopy revealing the formation of pairs [18]. However, while the experiments were consistent with superfluid behavior, they did not address properties unique to superfluids, i.e. hydrodynamic excitations can reflect superfluid or classical hydrodynamics, and the RF spectrum shows no difference between the superfluid and the normal state [18]. What was needed was a proof of superfluidity in atomic Fermi gases.

Observation of High-Temperature Superfluidity

In April 2005, fermionic superfluidity and phase coherence was finally demonstrated at MIT through the observation of quantized vortices. Superfluids are described by a macroscopic wavefunction $\psi(\boldsymbol{r})$, that is zero in the normal state and non-zero in the superfluid state. As a wavefunction, it is a complex quantity with a magnitude and phase ϕ:

$$\psi(\boldsymbol{r}) = |\psi(\boldsymbol{r})| \exp(i\,\phi)$$

The velocity of the superfluid is the gradient of the phase, $\boldsymbol{v} = \hbar \nabla\phi / m^*$, where m^* is the mass of the boson or fermion pair forming the superfluid. Integrating the velocity around a closed loop inside the superfluid, we immediately arrive at the Onsager-Feynman quantization condition for the circulation

$$\oint \boldsymbol{v}\cdot\mathbf{d}\boldsymbol{l} = n\, h/m^*$$

with integer n. If the superfluid wave function has no nodal lines and the loop lies in a simply connected region of space, we must have $n=0$. However, we can have $n\neq 0$ if the wave function contains a *vortex*, that is, a flow field that depends on the vortex core distance r like $v\sim 1/r$. At the location of the vortex, it has a nodal line. This is the way a superfluid carries angular momentum. Circulation is quantized in units of h/m^*. Note that vortices are a property of the superfluid in the ground state at given angular momentum. This is in marked contrast to *classical* vortices that exist only in metastable or non-equilibrium situations. Vortex patterns will ultimately decay into rigid body rotation whenever the viscosity is non-zero.

Vortices of equal charge repel each other. This immediately follows from kinetic energy considerations. Two vortices on top of each other double the velocities and quadruple the energy. Two vortices far separated have only twice the energy of a single vortex. As a result, vortices with charge $n > 1$ will quickly decay into singly charged vortices. If many vortices are created, they minimize the total kinetic energy of the cloud by arranging themselves into a regular hexagonal lattice, called Abrikosov lattice.

How can quantized vortices nucleate? Vortices cannot suddenly appear within the condensate, as the angular momentum contained within a closed loop inside the condensate cannot abruptly jump. Rather, the nodal lines have to enter the condensate from a *surface*, where the condensate's wave function is zero. This surface can also be the surface of a stirrer, if it fully expels the condensate.

In the MIT experiment, the stirrer is formed by two tightly focused, green laser beams that were symmetrically rotated around the trapped atomic cloud (Fig. 5). The laser light is blue-detuned with respect to the atomic resonance, and thus creates a repulsive potential for the atoms. The optical trap, formed by an infrared laser beam, has to be cylindrically symmetric and as smooth as possible. In other words, one has to “sand off the bumps of the bucket” in order to make the cloud rotate.

In the trap, the vortex size is on the order of the healing length (for an atomic or a molecular BEC) or of the inverse Fermi wavevector (for a strongly interacting Fermi gas), about 200 nm. This small size is prohibitive for in-situ detection using optical techniques. Fortunately, angular momentum conservation allows vortices to survive the expansion of the condensate, which we can thus use as a ``magnifying glass''.

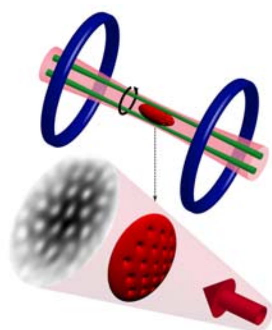

Fig. 5 Experimental Setup for the observation of Vortex lattices in ultracold Fermi gases. The gas is held in an optical trap (pink) in a magnetic field created by magnet coils (blue). Two additional laser beams (green) set the cloud in rotation. An absorption image of the expanded cloud shows the vortex lattice.

An additional complicatoin in the detection is due to the nature of the condensate in the BEC-BCS crossover: As the interactions are tuned from the BEC-side of the crossover towards the BCS-side, an ever smaller fraction of the gas is found in the condensate. In fact, in the BCS-limit, only an exponentially small number of atom pairs contributes to the coherent condensate wavefunction. The vortex contrast decreases dramatically. This can be overcome by ramping the interaction strength during expansion toward the BEC-side of the

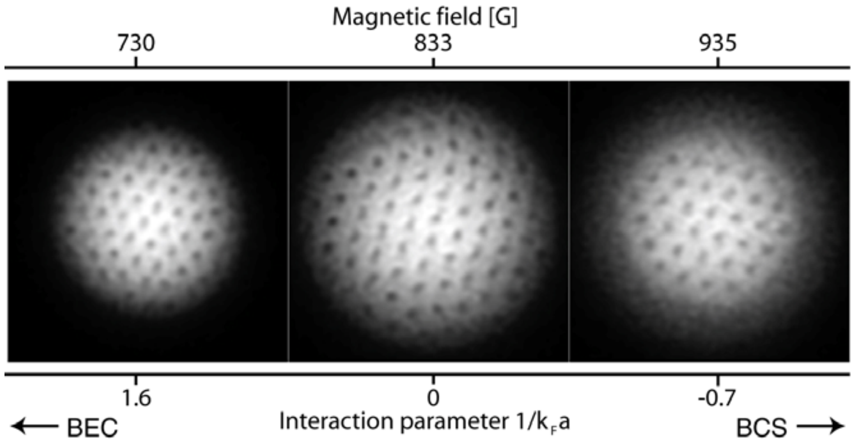

Fig. 6 Vortex lattices in the BEC-BCS crossover of an ultracold Fermi gas of atoms. The images show the gas clouds after expansion from the trap, for different values of the interaction parameter $1/k_F a$ within the BEC-BCS crossover. From [1].

resonance, where the vortex contrast is large and the vortices are easy to detect.

Fig. 6 shows the resulting vortex lattices in the BEC-BCS crossover of an ultracold Fermi gas of atoms [1]. These images demonstrate superfluidity and phase coherence in gases of molecules and of fermion pairs. The regularity of the lattice proves that all vortices have the same vorticity. From their number, the size of the cloud and the quantum of circulation $h/2m$ for each vortex, we can estimate the rotational frequency of the lattice. For an optimized stirring procedure, we find that it is close to the stirring frequency.

Apart from demonstrating superfluidity, vortices have been used to map out the phase diagram of imbalanced Fermi mixtures (see next section) and to study the breakdown of superfluid flow during expansion on the BCS-side of the resonance [18].

Fermionic Superfluidity with Imbalanced Spin Populations

Whether it occurs in Superconductors, ^{3}He or inside Neutron stars, fermionic superfluidity requires pairing of fermions. What, however, happens if we deliberately imbalance the populations in the two spin states? In this case, not every spin up (majority) fermion can find a spin down (minority) partner. Immediately, several questions arise: Can the gas still be superfluid? If so, are the excess fermions tolerated inside the gas of pairs or are they expelled from the superfluid? If superfluidity breaks down, what is the nature of such a strongly interacting, imbalanced normal mixture?

These questions cannot be answered in typical superconductors. To imbalance spin up versus spin down electron densities would require a magnetic field, but that field cannot enter due to the Meissner effect, a direct consequence of the electron charge. It can only enter in the form of quantized magnetic flux lines, the vortices.

Ultracold fermionic gases of atoms are neutral, so that effects on the spatial wavefunction, like rotation and vortices, are decoupled from their internal spin degrees of freedom. They thus allow us to freely choose the number of spin up versus spin down atoms used in the experiment, offering access to a new and unexplored part of the phase diagram of Fermi mixtures.

We studied this phase diagram in our strongly interacting Fermi mixture by varying the spin imbalance, temperature and interaction strength (see **Error! Reference source not found.**). Superfluidity was found to be robust against population imbalance in the strongly interacting regime [2]. We could show that, below a certain temperature, the superfluid state requires equal spin densities, and phase separates from the partially polarized normal state [19]. At a critical population imbalance, we observed the final breakdown of the superfluid state, the Clogston or Pauli limit of superfluidity. Studying imbalanced Fermi mixtures enabled us to directly observe the superfluid transition in situ, without any magnetic field ramps into the molecular regime [20]. RF spectroscopy [18] allowed us to study the nature of pair correlations and interactions in the normal state in the imbalanced regime [3].

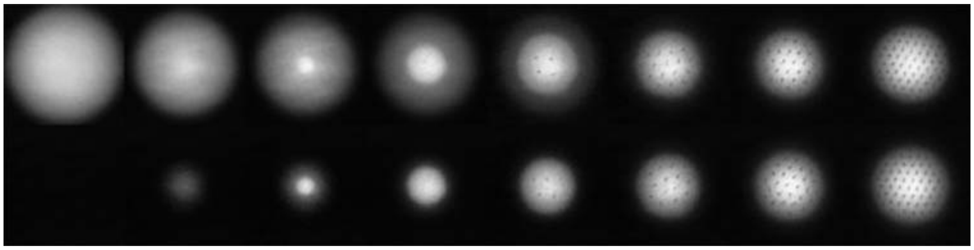

Fig. 7 Fermionic Superfluidity in imbalanced Fermi mixtures. The top and bottom row show absorption images of atoms in “spin up” and “spin down” at a magnetic field around the Feshbach resonance .

While the physics of an equal Fermi mixture with varying interaction strength was a smooth BEC-BCS crossover, imbalanced mixtures provide us with a much richer phase diagram, including zero temperature phase transitions, which challenges present many-body theories.

Fermi Polarons in a Tunable Fermi Liquid of Ultracold Atoms

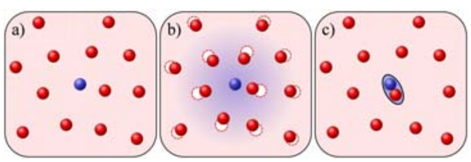

Fig. 8 From polarons to molecules. a) For weak attraction, an impurity (blue) experiences the mean field of the medium (red). b) For stronger attraction, the impurity surrounds itself with a localized cloud of environment atoms, forming a polaron. c) For strong attraction, molecules form despite Pauli blocking from the environment.

An intriguing limit of imbalanced Fermi mixtures is reached when one is left with just a few mobile “impurities” in a Fermi sea of “environment” atoms. In such a highly imbalanced mixture of fermionic atoms, we have observed so-called Fermi polarons using tomographic RF spectroscopy [4]. Feshbach resonances again allow to freely tune the interactions between the two spin states involved. A single spin down atom immersed in a Fermi sea of spin up atoms can do one of two things (see Fig. 8): For strong attraction, it can form a molecule with exactly one spin up partner, but for weaker interaction it will spread its attraction and surround itself with a collection of majority atoms. This spin down atom "dressed" with a spin up cloud constitutes the spin-polaron. We have observed a striking spectroscopic signature of this quasi-particle for various interaction strengths, a narrow peak in the spin down spectrum that emerges above a broad background. The narrow width signals a long lifetime of the Fermi polaron, much longer than the collision rate with spin up atoms, as it must be for a proper quasi-particle. The peak position allows to directly measure the polaron energy. The broad pedestal at high energies reveals physics at short distances and is thus "molecule-like": It is exactly matched by the spin up spectra. The comparison with the area under the polaron peak allows to directly obtain the quasi-particle weight Z.

We observe a smooth transition from polarons to molecules. At a critical interaction strength of $1/k_F\, a = 0.7$, the polaron peak vanishes and spin up and spin down spectra exactly match, signalling the formation of molecules. This is the same critical interaction strength found earlier to separate a normal Fermi mixture from a superfluid molecular Bose-Einstein condensate.

The spin-polarons determine the low-temperature phase diagram of imbalanced Fermi mixtures. In principle, polarons can interact with each other and might, at low enough temperatures, form a superfluid of p-wave pairs. The question of the ground state of imbalanced Fermi mixtures is still open.

Outlook

Ultracold atomic Fermi gases allow us to explore a very unusual richness of phenomena, from low-viscosity hydrodynamic behavior, fermionic superfluids, Fermi mixtures with population imbalance, zero temperature phase transitions etc. Many patches of this phase diagram have not yet been explored experimentally, and there remain controversies on the ground state of imbalanced Fermi gases in the different limits of interaction strength. Most importantly, the phase diagram of attractively interacting Fermi mixtures in optical lattices will directly impact the fermionic Hubbard model with repulsive interactions. Indeed, there is a remarkable mapping between these two major unsolved problems of condensed matter physics. What is found in one regime (for attractive interactions) will directly impact the other (repulsive interactions). At this point, any prediction of what physics ultracold Fermi gases might uncover in the future will soon be outdated. It is fascinating that Nature has given us this amazing system to work with, where essentially every parameter can be tuned at will. She has indeed been very kind to us.

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